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CHEMICAL SECTION.

Stated Meeting of March 19, 1895.

DR. W. C. DAY, President, in the Chair.

[The President announced the paper for the evening, and introduced the speaker.]

COMPOSITION OF THE AMERICAN SULPHUR PETROLEUMS.

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[*Concluded from vol. cxxxix, p. 424.*]

OHIO PETROLEUM.

Aside from our own publications on the sulphur compounds in Ohio oil (*Proc. Amer. Acad.*, **25**, 218; *Amer. Chem. Journ.* **16**, 83), and those of Orton (Ohio State Geological Reports for 1886, 1888, 1890; and United States Geological Report, 1886–87), I have seen no published statements concerning the composition of the Ohio sulphur petroleum. The crude oil, that has formed the basis of this work, was received from the Peerless Refining Company, Findlay, O.,

which controls a large section of oil territory. This oil was somewhat thicker in consistency than Pennsylvania oil, with a slight odor of hydric sulphide, and it contained a small quantity of water which was slowly removed by fused calcic chloride. Its specific gravity at 20° was found to be 0·838.

A determination of sulphur gave 0·72 per cent., a value somewhat higher than we have hitherto obtained, 0·55 per cent. Markownikoff and Ogloblin obtained in Apsheron petroleum 0·064 per cent. and in the Transcaspian oil 0·16 per cent.

A combustion in oxygen with a layer of plumbic peroxide in front to retain the sulphur (Warren, *Proc. Amer. Acad.*, **6**, 472) gave the following percentages of carbon and hydrogen: Carbon, 84·57; Hydrogen, 13·62.

Bromine absorption in the crude oil and in some of the fractions was determined by the method given in Allen's *Commercial Organic Analysis*, Vol. II, page 388, with the following results:

Fraction.	*Percentage of Bromine Absorbed.*
110°–150°	0·73
150°–220°	1·74
220°–257°	4·84
257°–300°	5·04
300°–330°	12·1
Residue	19·5

A determination of the bromine absorption in the crude oil gave 6·1 per cent.

The distinctive qualities of Ohio oil appear also in the proportions which distill at different temperatures; 800 grams of the crude oil distilled in the following proportions, beginning at 110°:

	110°–150°	150°–220°	220°–257°	257°–300°	300°–350°	Residue
Grams	76	133	86	76	69	348
Per cent.	9·75	16·63	10·75	9·75	8·63	43·5
Sp. Gr. at 20°	0·7282	0·7669	0·7940	0·8138	0·8242	0·8976
Per cent. sulphur	0 10	0·38	0·41	0·37	0·37	0·54

The distillates below 225° were not appreciably decomposed, since they were free from color and odors resulting from decomposition. At somewhat higher temperatures

the distillates were colored, with characteristic penetrating odors. It was, therefore, evident that in the refinery distillation of Ohio oils cracking begins in the vicinity of 250°. There is evidence that certain extremely unstable constituents of the crude oils, when separated, decompose on standing, and no doubt similar decompositions take place, perhaps more slowly, when they are dissolved in other portions of the oils. At the beginning of the distillation, hydric sulphide appears to some extent, but the higher fractions are nearly free from it. Considerable sulphur is lost during distillation, as shown by analyses of the crude oil and of products obtained from it. In determining experimentally what became of the sulphur evolved, it appeared to escape mainly as hydric sulphide, with the separation in small quantity of free sulphur and perhaps in still smaller quantities as volatile sulphur compounds.

The ash obtained by igniting the residue from the distillation of the volatile portions of petroleum, has frequently been examined. Traces of metals, gold, silver and copper have been found, as well as the oxides of calcium, iron and aluminum. In the ash of Caucasus petroleum Markownikoff and Ogloblin found substantially the same composition, and the quantity of ash calculated for the original quantity of crude oil amounted to 0·09 per cent. In the coke from Ohio petroleum, we have found 95·06 per cent. of carbon, 4·85 per cent. of hydrogen, and 0·11 per cent. of ash.

It has already been mentioned that all petroleums are regarded by some chemists as having a similar composition, the difference in properties depending upon a variation in the proportions of the constituents. The Caucasus petroleum contains but a small proportion of the series C_nH_{2n+2}, and the Pennsylvania oil, so far as it has been examined, contains the series C_nH_{2n} in much smaller proportions than the Russian oil. Referring the sulphur in Ohio petroleum to the average composition of the compounds containing it, the sulphur derivatives should amount to at least five per cent. of the crude oil. Such a proportion of sulphur compounds must necessarily exert an important influence on the properties of the crude oil as well as of the products ob-

tained from it. To ascertain, therefore, the relation in which the Ohio sulphur oil stands to the other two petroleums in question, it seemed necessary to submit the Ohio product to an examination for all constituents. We have undertaken to determine first the presence of the hydrocarbons C_nH_{2n+2}, with the approximate quantity of each member of this series, except those with low boiling points.

HYDROCARBONS C_nH_{2n+2}.

For the separation of the members of this series, we procured twenty-five liters of the most volatile refinery distillates collected from a 300-barrel still. This product was subjected to distillation in quantities of eight liters each, with the aid of a Warren condenser filled with a mixture of salt and ice, ice alone or water dependent upon the boiling point of the distillate collected, placing in front of the condenser another containing the freezing mixture. To collect any gas that might escape during the distillation, a delivery tube dipping beneath an inverted receiver filled with water was connected to the bottle receiving the distillate. At first, a very small quantity of gas collected, which burned with a smoky flame, but none afterward. In refinery distillation of the Ohio oil, gases escape in considerable quantities before distillates condense, but we have not yet examined them. With the exception of hydric sulphide, probably these gases do not differ essentially from those which are evolved at the beginning of the distillation of Pennsylvania oil. I am not aware that the composition of the gas from Ohio oil wells has been determined, but it is probably not very different from that of the gas issuing from the Pennsylvania wells which Sadtler (*Amer. Chem.*, **7**, 97) found to consist principally of methane, with smaller quantities of ethane, hydrogen, carbon dioxide and nitrogen. In the gas from the Canadian wells at Enniskillen, Fouqué (*Compt. Rend.* **67**, 1045) found marsh gas, ethane, and small quantities of carbonic dioxide.

The first distillates were subjected to further distillation until a considerable quantity collected that distilled tolerably constant within narrow limits of temperature, corre-

sponding to the boiling points of the hydrocarbons. Between 0° and 1°, 35 grams collected, which distilled for the most part at 0°, barometer 741 mm., corresponding to the boiling point of butane. At 7°-9°, 20 grams of a distillate collected, corresponding to the hydrocarbon which was separated by Warren from Pennsylvania petroleum, and which he regarded as one of the butanes. Of the two possible butanes there can be no doubt that one boils at 0°, and Butlerow (*Ann. Chem. Pharm.* **144**, 10) obtained from isobutyl alcohol a butane to which he assigned as the boiling point —17°·5. Since, therefore, there seems to be some question concerning the product which he collected at 8°, more of this distillate will be procured for the study of its chemical behavior to ascertain whether it be a definite compound.

Between 29° and 30°, barometer 747 mm., the distillate amounted to 75 grams, and a vapor density determination gave the value required for isopentane; found 2·52, required for pentane, 2·49. At 37°-38°, 75 grams distilled, and this product gave as its vapor density, 2·49; required for normal pentane, 2·49. At 60°-61°, 50 grams collected, which gave a vapor density required for isohexane; found, 2·94; required, 2·98. The quantity of product collected at 67°-68° gave as its vapor density, 3·00; required for normal hexane, 2·98. On account of the manner in which these distillates were collected, the weights afford no information concerning the proportions in which they are contained in the crude oil, although they are evidently present in much smaller quantities than in Pennsylvania oil.

For the separation of the hydrocarbons with higher boiling points, the fraction —150° from the crude oil distilled *in vacuo*, was submitted to further distillation under atmospheric pressure. 41·5 kilos of crude Findlay oil was distilled under a tension of 50 mm., and products separated within the limits —100°, 100°-150°, 150°-200°, 200°-250°, 250°-350°, and the residue above 350°, which was preserved. These products collected with but slight decomposition and without the disagreeable odors characteristic of refinery distillates. On account of the reduced pressure, doubtless some of the more volatile constituents were lost, and in

subsequent operations scarcely any distillate collected below 30°. Within these limits the distillate collected in the following proportions:

	–100°	100°–150°	150°–200°	200°–250°	250°–350°	Residue.
Grams	8000	8520	6480	7700	2670	9000
Per cent. .	18·6	19·8	15·1	18·	6·2	20·9

The following results were obtained in determining the specific gravity of the distillates:

–100°	100°–150°	150°–200°	200°–250°	250°–350°	Residue.
0·7445	0·7941	0·8245	0·8455	0·907	0·9139

No hydric sulphide was detected in the fraction —100°, but it was present in small quantities in the higher fractions. The percentages of sulphur were determined by combustion in air,

	–100°	100°–150°	150°–200°	200°–315°	Residue.
Percentage of sulphur	0·054	0·25	0·42	0·61	0·67

A comparison of these results with the percentages of sulphur in the distillates collected under atmospheric pressure (see p. 2) shows the influence of distillation *in vacuo*, diminishing the quantity of sulphur in the lower products. This is one of the desirable features of vacuum distillation for the sulphur petroleums.

The portion collected below 150° in the first distillation was submitted to a series of separations under atmospheric pressure with the aid of Hempel and Warren condensers. In successive distillations collecting within 5°, within 2°, and finally within 1°, the distillates collected rapidly within limits of temperature corresponding to the boiling points of the well-known hydrocarbons C_nH_{2n+2}, and at certain other points where an equilibrium in boiling points seemed to be established by mixtures of lower and higher products. To separate the constituents of such mixtures required long-continued distillations, but for the most part it was evident that they corresponded to no individual hydrocarbons. In purifying the distillates containing the hydrocarbons for determination of vapor density, they were first shaken with alcoholic mercuric chloride to remove the sulphur compounds. The sulphur remaining in solution after this treat-

ment was usually less than 0·03 per cent., provided the compound, R_2SHgCl_2, was crystalline, as was observed in most of the fractions below 150°. In fractions with higher boiling points the mercury is held in solution, either as the molecular compound of the sulphide or in some other combination, with such persistence that it can be removed only by the prolonged action of hydric sulphide on the hot distillate. In some of the sulphur oils hydric sulphide in the cold will not precipitate the mercury. This solvent action of the sulphur oils on metals, metallic oxides and certain other compounds seems to be a characteristic property which has also been observed in other petroleums. Macadam (*Journ. Chem. Soc.*, **34**, 355) ascertained that certain metals, such as lead, solder and zinc, are quite readily acted upon, and that some oils exert a greater solvent action than others. This solvent action was attributed by Macadam to the hydrocarbons, but Engler (*Ber. der deutsch. Gesellsch.*, **12**, 2186) repeated the experiments of Macadam and ascertained that metals are not affected when air is excluded. Engler, therefore, concluded that acid compounds are formed in the oil by exposure to air which dissolves metallic oxides. Without doubt the purification of refined distillates from the sulphur petroleum by agitation with an alkaline solution of plumbic oxide depends, in part, at least, upon the solvent action of certain constituents of the oil. It may be that the solvent action is due to the combined effect of the oxygen and the sulphur compounds, assuming, of course, that oxygen compounds are contained in the sulphur petroleums which, from the analogy of other oils, may, at least, be regarded as probable. This subject will receive further attention when we reach the higher distillates.

For further purification each fraction was agitated, first with concentrated nitric, then with concentrated sulphuric acid, and finally heated for some time under a vertical condenser with metallic sodium. The fractions in the vicinity of 80° will be considered with the aromatic series. The distillate collected at 89°–90°, barometer 754 mm., gave a vapor density 3·43, corresponding to that of isoheptane, 3·46. At 96°–97°, 50 grams distilled constant, barometer 744 mm.,

and the vapor density of this product was found to be 3·42; required for heptane, 3·6. No other oils were collected in any considerable quantity below 109°, the point where toluol began to appear. Fifty grams distilled constant at 119°–120°, barometer 749 mm., and gave as its vapor density 3·89; the vapor density required for octane is 3·94. Since there seems to be some doubt concerning the existence of an octane at this point, this fraction was carefully purified in the manner described above, followed by prolonged boiling with sodium. Determinations of carbon and hydrogen, and of vapor density gave results agreeing closely for values required for octane. As further proof of the existence of a hydrocarbon with this boiling point, a considerable quantity has been prepared for the purpose of trying the action of a chlorine and the formation of other derivatives.

Warren (*Mem. Amer. Acad.* (N. S.), **9**, 156) separated a constituent of Pennsylvania petroleum which distilled constant at 119°·5, with a vapor density corresponding to that of octane. From the particular care with which the determinations of Warren were made, there can be no doubt concerning the existence of a hydrocarbon in Pennsylvania petroleum with this boiling point. Although Beilstein and Kurbatoff recognized hexahydroisoxylol in a distillate of Pennsylvania petroleum collected at 119°·5, it is probably not the principal constituent with this boiling point; it certainly does not constitute the main portion of this fraction in Ohio petroleum. In a distillate from coal Schorlemmer (*Journ. Chem. Soc.*, **15**, 419) separated an octane boiling at 119°–120°, and subsequently (*Ann. Chem. Pharm.*, **127**, 311) he identified the same body boiling at 119° in petroleum. But in the treatise on Chemistry, by Roscoe and Schorlemmer, New York, 1886, it is stated that the three octanes known are: normal octane, boiling point 125°·46, found in petroleum; tetramethylbutane, boiling point 108°·5; and hexamethylethane, melting at 96°–98° and boiling at 105°–106°.

Above 120°, after the eleventh distillation, the distillates collected in considerable quantities within the limits of 1°:

120°–121°	121°–122°	122°–123°	123°–124°	124°–125°	125°–126°	126°–127°	127°–128°
grams 35	40	80	70	75	75	60	40

After prolonged distillation considerable quantities still collected at 122°–125°, and they contained a small quantity of aromatic hydrocarbons. We are collecting larger quantities of these oils for study of their behavior towards chemical reagents. The greater portion of the fractions 125°–130° were lost in an accident after the eleventh distillation; but sufficient was preserved, distilling at 127°–128°, for a vapor density determination which gave 3·85; required for C_8H_{18}, 3·94. The liquid collected between 127°–128°, by Warren at this point, was found to have the boiling point 127°·6; the vapor density found by Warren was 3·99.

All the distillates between 115° and 130° evidently need to be carefully examined with larger quantities of oil. The portion collected at 130°–145° will be considered in connection with the aromatic compounds.

The fractions collected between 144°–148° were small in quantity after long-continued distillation. Eighty-five grams were collected at 149°–151°, of which forty grams distilled constant at 149°–150°, barometer 756 mm., and a vapor density determination gave 4·63, required for C_9H_{20}, 4·43; boiling point of nonane 150°·8 (Warren). Below this point, Ohio sulphur petroleum seems to contain members of the series C_nH_{2n+2}, corresponding to those which have been recognized in Pennsylvania oil, but in smaller quantities. They form one-fifth of the crude Pennsylvania oil and but one-tenth of the Ohio oil. It has not seemed necessary to obtain further evidence than is necessary to show the similarity of the Ohio products with those which have been found in the Pennsylvania oil. This portion of our work may seem to possess less interest than the study of the higher boiling fractions, yet it has appeared of sufficient importance to justify the necessary expenditure of time and effort. The higher fractions have been quite thoroughly distilled, and these products, with the residue above 350° of the first vacuum distillation, are reserved for future study.

AROMATIC HYDROCARBONS.

Series C_nH_{2n-6}.

Benzol.—After the sixth distillation, 25 grams collected at 77°–79°, 35 grams at 79°–81°, and 20 grams at 81°–83°. Ben-

zol was determined in these fractions by treating a weighed quantity with a mixture of nitric and sulphuric acids, distilling off the hydrocarbons not affected and weighing them and the residual nitrobenzol. The fraction 77°–79° gave 3 per cent. of benzol; the fraction 79°–81°, 15 per cent.; and the fraction 81°–83°, 5·8 per cent. The fractions 75°–76° and 85°–86°, when treated in the same manner, left scarcely any residual nitro-product after distillation, and the slight residue gave no reaction for aniline with furfurol after reduction with tin and hydrochloric acid and distillation. This quantity of benzol, calculated for the 41·5 kilos of crude oil taken, amounts to 7·16 grams, or 0·017 per cent., which represents approximately the quantity of benzol in the crude oil.

Toluol.—In examining the fraction 107°–113° after the sixth distillation for toluol, a weighed quantity of the oil was treated with nitrosulphuric acid, keeping the solution cold. On standing, crystals of dinitrotoluol separated, which were identified by their melting-point, 71°. The portion of the oil not affected by the acid was removed by distillation, and the quantity of toluol corresponding to the residual hydrocarbon was 1·14 per cent. of the total distillate in the fraction 107°–109°, to 13·07 per cent. in the fraction 109°–111°, and 2·8 per cent. in the fraction 111°–113°; the total weight of the first fraction was 50, of the second 80, and of the third 65 grams. The total weight of toluol was, therefore, 12·84 grams, corresponding to 0·03 per cent. in the 41·45 kilos of crude oil, which may be accepted as the approximate quantity of toluol in Ohio petroleum. The fraction 114°–115°, when treated in a similar manner, gave a nitro-product which was apparently unchanged by reduction, since it would not dissolve in acids; it must, therefore, be derived from another series, perhaps from an unsaturated hydrocarbon, C_nH_{2n}.

Xylols.—Metaxylol has been identified in various petroleums, having been found first together with other homologues of benzol by De la Rue and Müller (*Proc. Roy. Soc.*, 1856, 221) in the Rangoon petroleum. Of the other isomeric xylols only the para-compound has been recognized, and that by Pawlewski in Galician petroleum.

Our products were collected, after twenty distillations, at intervals of 1° between 136° and 142°, the greater portion distilling at 137°–138°, 139°–140° and 141°–143°. These fractions were readily acted upon by nitric acid, forming nitro-compounds or oxidation products according to the form of the reaction. In testing for the presence of para-xylol in fraction 137°–138°, a portion was treated with a mixture of nitric and sulphuric acids, at first in the cold, then with the aid of a gentle heat. After distillation of the portion not affected, a brown oil remained, which deposited a crystalline solid on standing, and, after crystallization from alcohol, a substance formed in glistening white needles melting at 139°–140°. It was, therefore, trinitro-p-xylol, melting-point 139°–140° (Nölting and Geissmann, *Ber. der deutsch. chem. Gesellsch.*, **19**, 144). Another portion of the same fraction with fuming nitric acid in the cold gave long, yellow needles, sparingly soluble in alcohol, melting at 145°; therefore, dinitro-p-xylol, melting-point 147°–148° (Lellman, *Ann. Chem. u. Pharm.*, **228**, 250). For further confirmation, more of the same oil was boiled for some time with chromic acid, and the solution extracted with a considerable quantity of ether. The solid remaining after evaporation of the ether appeared in the form of minute prisms which were insoluble in water, but dissolved readily in sodic hydrate, and sublimed without melting. The properties of this substance, therefore, corresponded to those of terephthalic acid. Another portion of the same oil when heated thirty hours, after distillation of the hydrocarbon not affected, left only an oily product. Upon heating a much longer time the oily residue was neutralized with sodic hydrate evaporated to dryness, the salt decomposed with hydrochloric acid, and the solution extracted with ether; the crystalline solid left by evaporation of the ether was probably p-toluic acid, but it was not obtained in quantity sufficient for identification.

Metaxylol.—After heating a portion of the fraction 139°–140° with a mixture of nitric and sulphuric acids during forty-eight hours, and distilling the oil not affected by the acids, the solid which remained, together with the crystals

collected on cooling the acid mixture, was purified by crystallization from hot alcohol; the long, slender, colorless needles thus obtained melted at 175°–176°, showing its identity as trinitro-m-xylol, melting point 176°.

In the fraction 141°–143° several attempts were made to ascertain the presence or absence of orthoxylol, but the nitro-products and the acids resulting from oxidation were not obtained in sufficient quantities to distinguish them from the corresponding derivatives of metaxylol.

Approximate quantitative determinations of the xylols showed that they were present in the crude oil in very small proportions. In the fraction 137°–138°, the quantity of paraxylol corresponded to 0·021 per cent. in fraction 139°–140°, the quantity of metaxylol to 0·016 per cent. The quantity of xylol found in the distillates 142°–143° corresponded to 0·021 per cent. of the crude oil; and, since the presence of orthoxylol is doubtful, the xylol in these fractions was probably the meta-compound. Although the distillation of these portions was long-continued, the xylols were evidently not all collected in their respective fractions. At least one-third should be added to the percentages given above from outside sources.

There were indications in the distillates 130°–140° of other constituents capable of forming nitro-products, perhaps ethylbenzol and hexahydromesitylene. Attempts were made to identify these bodies, but the quantities of the distillates were insufficient. Further examination for these bodies will be made with larger quantities.

SERIES C_nH_{2n}.

Hexahydro compounds (Beilstein and Kurbatoff); naphtenes (Markownikoff and Ogloblin).

This series of hydrocarbons, so far as they have been investigated, include the following members:

	Boiling Point.
Hexahydrobenzol (C_6H_{12})	69°
Hexahydrotoluol (C_7H_{14})	96°
Hexahydroisoxylol (C_8H_{16})	118°
Hexahydromesitylene (C_9H_{18})	135°–138°
Hexahydrocumol (C_9H_{18})	147°–150°
Hexahydrocymol ($C_{10}H_{20}$)	171°–173°

In examining the distillates from Ohio petroleum for the hydrocarbons of this series, beginning with hexahydrobenzol, the fraction 69°–70°, after the fourteenth distillation, was shaken with concentrated nitric acid, with concentrated sulphuric acid, and then heated to boiling with metallic sodium. Determinations of carbon and hydrogen in the oil thus purified gave results corresponding to the composition of hexane:

I. 0·1618 gram of the oil gave 0·4934 gram CO_2 and 0·2299 gram H_2O.

II. 0·1891 gram of the oil gave 0·5790 gram CO_2 and 0·2663 gram H_2O.

	Required for		Found.	
	C_6H_{14}	C_6H_{12}	*I.*	*II.*
C	83·72	85 71	83·18	83·51
H	16·28	14·28	15·79	15·65

Hexahydrobenzol is therefore not present in Ohio oil.

The fraction 96°–97°, barometer 750 millimeters, after the fourteenth distillation, was purified as before, and its composition determined by analysis:

0·2083 gram of the substance gave 0·6423 gram CO_2, and 0·2849 gram H_2O.

0·2010 gram of the substance gave 0·6200 gram CO_2, and 0·2744 gram H_2O.

	Required for.		Found.	
	C_7H_{16}	C_7H_{14}	*I.*	*II.*
C	84·00	85·71	84·09	84·72
H	16·00	14·28	15·27	15·17

This oil was evidently heptane, C_7H_{16}, the low percentage of hydrogen indicating perhaps a trace of hexahydrotoluol. Another portion of the fraction was then boiled for some time with a mixture of nitric and sulphuric acids, distilled over sodium and analyzed. The percentage of carbon and hydrogen corresponded to the composition of heptane: Carbon, 83·75; hydrogen, 16·28.

In a distillate 95°–100° from American ligroine, Beilstein and Kurbatoff found 84·3 per cent. of carbon and 15·4 per cent. of hydrogen. After prolonged heating with dilute nitric acid, the oil distilled at 98°·5–99°·5, and gave, on analysis, 84·2 per cent. of carbon and 15·9 per cent. of

hydrogen, from which it was inferred that hydrocarbons poorer in hydrogen, were contained in the crude ligroine.

Hexahydroisoxylol (Octonaphtene, Markownikoff).—Hexahydroisoxylol was found by Beilstein and Kurbatoff in Caucasus petroleum (*Ber. der deutsch. chem. Gesellsch.*, **13**, 1818), and in American ligroine (*ibid*, **13**, 2028); since the American source was not mentioned, it is to be inferred that the ligroine was prepared from Pennsylvania oil. In testing the fraction 118°–119°, fourteenth distillation, for hexahydroisoxylol, a portion of the oil was heated forty hours with a mixture of nitric and sulphuric acids. On cooling, long, flat plates separated from the oil, nearly insoluble in cold, more readily in hot alcohol. After crystallization from alcohol, this substance melted at 178°, and was, therefore, trinitroisoxylol. A similar nitro-product, with the same melting point, was obtained from the fraction 123°–124°. There can be no doubt that the trinitroxylol obtained from fraction 118°-119° indicated the presence of hexahydroisoxylol since the prolonged distillation precluded the possibility that this fraction contained metaxylol. As it appeared in the study of this fraction, hexahydroisoxylol was present only in very small quantity.

After agitating thoroughly a portion of the same distillate with a mixture of nitric and sulphuric acids, and distilling over sodium, analysis gave percentages of carbon and hydrogen required for octane:

	REQUIRED FOR		FOUND.	
	C_8H_{18}	C_8H_{16}	*I.*	*II.*
C	84·20	85·71	84·42	84·28
H	15·79	14·28	15·19	15·08

Since the percentage of hydrogen is somewhat too low, it is possible that the hexahydro-compound was not entirely removed by the treatment with acids, especially as we have found that prolonged heating with the acid mixture is necessary even to form a crystalline nitro-product.

In describing the properties of hexahydroisoxylol, Wreden found that it was readily converted by a mixture of nitric and sulphuric acids into trinitro-meta-xylol, and Baeyer made a similar observation concerning hexahydrome-

sitylene. On account of the slow formation of the nitro-derivative in the oil separated from petroleum, Markownikoff doubted the identity of octonaphtene and hexahydroisoxylol. There seems to be no difficulty in forming the nitro-compound, at least in the oils we have in hand, although considerable time is required for its formation, possibly due to the dilution by other constituents.

After long-continued boiling of this distillate with the acid mixture, followed by successive treatment with sodium until distillation left no residue, analysis gave results required for octane:

Carbon, 84·20; hydrogen, 16·10.

CANADIAN PETROLEUM.

Under the general title of American petroleum, with occasional reference to Pennsylvania and to Canada as the particular sources, several partial examinations were early made of crude Canadian oil by French and English chemists. Pelouze and Cahours were the first to establish the presence of the series C_nH_{2n+2}, and Schorlemmer recognized the presence of benzol, toluol and cumol in "real Canadian rock oil, a thick black liquid of a very unpleasant odor."

My first acquaintance with Canadian petroleum was in 1890, when I procured some of the crude oil and also a quantity of the "sludge" from the refining of burning oil for the purpose of examining the sulphur compounds. The peculiar features of the distillates in a preliminary examination (*Am. Chem. Journ.*, **16**, 89) seemed especially inviting, and I decided to undertake, with the aid of the refiners, as complete an examination for the principal constituents as was possible with the appliances at my command.

The products which I obtained from the refinery of Messrs. Samuel Baker & Co., at Petrolia, for the study of Canadian petroleum, included a barrel of crude oil, considerable quantities of the first distillate, naphtha distillate, and burning oil distillate, none of which had been further refined, besides 200 litres of thoroughly washed oil from "sludge acid." The crude oil was thick and nearly black in color, with the peculiar penetrating odor characteristic of the

sulphur oils. It contained hydric sulphide in small quantity and some water, which was removed after long standing with fused calcic chloride. A determination of the specific gravity of the crude oil at 20° gave 0·8821. A former determination in another sample of crude oil gave 0·8600 (Mabery, *Am. Chem. Jour.*, **16**, 90). These results differ widely from certain others hitherto reported. H. P. Brummel (*Can. Geol. Rep.*, 1888, 89) gave, as the specific gravity of Canadian oil, 0·804 and 0·808. Markownikoff and Ogloblin (*Ann. Chim. Phys.*, VI, **2**, 372) referred to results by Deville which gave 0·844 as the specific gravity of Canadian oil, and 0.887 as the specific gravity of Ohio oil. The specific gravity of the oils at Petrolia was given by Redwood (*Journ. Soc. Chem. Ind.*, 1887, 405) as 0·859–0·877, and of those at Oil Springs somewhat lower, 0·844–0·854. We found the specific gravity of the latter oil to be essentially the same—0·8442. Probably, as Engler observed in the Elsass oils, the specific gravity diminishes with the depth of the well.

Determinations of sulphur in the crude oil gave the following results:

	I.	II.	III.
Per cent. Sulphur,	0·98	0·99	1·06
	(By Carius.)	(By combustion in air.)	

The Canadian petroleum contains somewhat less carbon and hydrogen than Ohio sulphur oil:

	Canadian.	*Ohio.*	*Pennsylvania.*	*Russian.*
C	83·94	84·57	84·19	86·89
H	13·37	13·62	13·70	13·18

In the Canadian Geological Report, 1888–1889, Brummel gave eighty-five per cent. for carbon and fifteen per cent. for hydrogen, but these results are evidently only approximately correct. The percentages of carbon, hydrogen and oxygen in Canadian oil, as found by Pelouze and Cahours, are as follows:

	C.	H.	O.
I	84·2	13·4	2·3
II	84·3	13·5	2·0

In a distillation of the Canadian oil under atmospheric pressure, the following weights were obtained from 800 grams, the distillation beginning at 115°:

	115°–150°	150°–200°	200°–250°	250°–300°	300°–350°	Residue.	Loss.
Weights . .	22	62·5	72	43	27	561	12
Per cent. .	2·75	7·8	9·5	5·1	3·1	70·1	1·75
Specific Gravity,	0·767	0·8026	0·8228	0·8345	0·9037		

A comparison of the distillates at different temperatures of oils from other localities has been included in considering the properties of the Ohio oil. A clearer idea may be gained of the peculiar character of the Canadian oil by comparing the distillates from it with those from other fields:

	Apsheron.		Pennsylvania.	
	Per Cent.	*Specific Gravity.*	*Per Cent.*	*Specific Gravity.*
120°–150° . .	0·5		19·75	
150°–200° . .	10·9	0·786	8·75	0·757
200°–250° . .	12·8	0·824	15·23	0·788
250°–320° . .	24·7	0·861	20·7	0·809
	47·9		64·43	
Residue . .	52·1		35·57	

	Canada.		Ohio.		
	Per Cent.	*Specific Gr.*		*Per Cent.*	*Specific Gr.*
115°–150°	2·75	0·767	110°–150°	9·75	0·7282
150°–200°	7·8	0·8026	150°–220°	16·63	0·7669
200°–250°	9·5	0·8228	220°–257°	10·75	0·7940
250°–300°	5·1	0·8345	257°–300°	9·75	0·8138
300°–350°	3·1	0·9037	300°–350°	8·63	0·8242
	28·25			55·51	
Residue . .	70·10			43·00	

In the percentages of the lower fractions it will be seen that the Canadian oil resembles more nearly the Russian oil, but the residue above 350° is somewhat larger than in the oils from other localities. As will appear later, this difference is much less in distillations conducted *in vacuo*.

The percentage of sulphur was determined in each distillate by combustion in air:

	115°–150°	150°–200°	200°–250°	250°–300°	300°–350	Residue.
Per cent. of sulphur,	0·28	0·42	0·50	0·51	0·86	0·70

Determinations of the quantity of bromine absorbed indicated slight differences in the capacity for absorption between the higher fractions and those from Ohio oil:

Canada.		Ohio.	
Fraction.	*Per Cent. of Br. Abs.*	*Fraction.*	*Per Cent. of Br. Abs.*
115°–150°	0·67	110°–150°	0·73
150°–200°	1·12	150°–220°	1·74
200°–250°	3·49	220°–257°	4·84
250°–300°	8·39	257°–300°	5·04
300°–350°	14·4	300° 330°	12·1
+350°	17·8	+330°	19·5

The percentage of bromine absorbed by the crude oils was nearly the same.

Canada.	Ohio.
15·11	10·19

Below 200° the decomposition was slight, the distillates were colorless and hydric sulphide escaped only in small quantities. Above this point the distillates began to appear yellow with the disagreeable odor of decomposition. It is probable that cracking begins near this temperature affecting the unsaturated hydrocarbons, if they are present, and perhaps other series as well as the sulphur compounds. Certain constituents of the Canadian oil seem to be more unstable than those of Ohio petroleum. The tendency towards polymerization of unsaturated hydrocarbons, separated from distillates corresponding to burning oil, was observed by me (*Amer. Chem. Jour.*, **16,** 92) in an oil that had stood two years after prolonged distillation. When again heated, it suddenly polymerized into a higher product that could not be distilled without decomposition. The conversion of Canadian petroleum into pitch, upon long standing exposed to the weather, may be observed at Oil Springs. It is probably caused by evaporation or absorption of the more volatile portions of the crude oil and polymerization of unstable constituents.

Determinations of carbon and hydrogen were made in a specimen of coke from Petrolia oil with the following results:

	Coke from Petrolia Oil.		Oil Springs Pitch.
	I.	*II.*	
C	94·04	94·34	64 86
H	4·19	4·34	8·13
Ash	0·17	0·066	10·13

Analysis No. I was of coke from crude oil, and No. II of coke from tar distillate.

The carbon was completely burned from another portion of the coke, No. II, and the weight of the ash ascertained. Since the quantity of the crude oil corresponding to the coke is ten times the coke from this determination, the percentage of ash in the crude oil may be taken as 0·0066. An examination of the ash showed that it was composed chiefly of calcic and magnesic oxides. It is interesting to note the presence of magnesic oxide in considerable quantities, indicating its dolomitic origin.

It is practically impossible to distill the Canadian oil in the ordinary method on a small scale, unless it is nearly free from water, and the water can only be completely removed by long standing with large quantities of calcic chloride. After the first distillation there is less difficulty in removing water except in the higher distillates. The necessity of vacuum distillation to avoid decomposition was even more evident in Canadian than in Ohio oil. In quantities of twelve liters each, 64·5 kilos were distilled in a porcelain still under a tension of fifty millimeters, and the following quantities of the distillates were collected at different temperatures:

	-100°	100°-150°	150°-200°	200°-250°	250°-300°	300°-350°	Residue
Grams . .	3870	7288	7159	8578	7869	6698	22059
Per cent.	6·00	11·3	11·1	13·3	12·2	10·4	34·2
					250°-350°		
Per cent. in Ohio oil.	18·6	19·8	15·1	18·0	6·2		20·9

The differences in the weights collected at different temperatures in Canadian and Ohio petroleum confirm the marked variation in composition already referred to. An explanation must evidently be sought in the larger quantities of the series C_nH_{2n+2} in the fractions below 150° from Ohio oil, and the greater quantity of the heavier oils of the series C_nH_{2n} and similar series in the portions above this point from the Canadian oil.

The percentages of sulphur in these distillates were also determined:

	-100°	100°-150°	150°-200°	200°-250°	250°-300°	300°-350°	Residue
Per cent. of Sulphur	0·25	0·45	0·47	0·75	0·78	0·81	0·83

When distilled without much decomposition, the sulphur compounds in the Canadian oil collect in smaller quantities in the lower distillates than is the case in the Ohio oil.

The distillates collected *in vacuo* showed but slight indications of decomposition; they were only slightly discolored, except the residue, above 350°, which had apparently undergone but little decomposition. The distillates above 150° and the residue above 350° are reserved for future study.

The vacuum distillate below 150° was fractioned twelve times, collecting at first within 5° then within 2° and finally within 1° limits, with the aid of a Warren condenser with glass coils and of Hempel columns. At the end of the eighth distillation eight grams collected below 55°. Of the portion between 55° and 60°, fifteen grams distilled constant at 60°–61°, barometer 741 millimeters, and a vapor density of the latter product gave 2·996; required for isohexane, 2·98.

At 67°–68°, after the twelfth distillation, ten grams of oil collected, which gave a vapor density of 3·01; required for hexane, 2·08. The distillates 75°–85° will be considered with the aromatic series. At the end of the fifteenth distillation, 20 grams distilled constant at 90°–91°, barometer 740 millimeters, and a vapor density determination of this product gave 3·50; isoheptane, C_7H_{14}, requires 3·46.

At 96°·5–97°·5, after the seventeenth distillation, barometer 740 millimeters, 80 grams collected that distilled constant within these limits, and its vapor density was found to be 3·63; required for heptane, 3·46. The composition of this oil was further established by analysis:

0·1870 gram of the oil gave 0·5781 gram CO_2 and 0·2514 gram H_2O.

	Required for C_7H_{16}.	*Found.*
C	84·00	84·31
H	16·00	15·77

Below 105°, the distillates were not in sufficient quantity to indicate definite compounds. The fractions containing toluol will be described later.

After long distillation, a fraction weighing 90 grams col-

lected constant at 118°–119°·5, with a vapor density of 4·02; required for octane, C_8H_{16}, 3·94. This fraction was purified with much care, in the same manner as the corresponding distillate from Ohio oil, and a combustion gave the following percentages of carbon and hydrogen:

(1) 0·2013 gram of the oil gave 0·6226 gram CO_2 and 0·2738 gram H_2O.

(2) 0·2036 gram of the oil gave 0·6318 gram CO_2 and 0·2799 gram $_2O$.

(3) 0·2045 gram of the oil gave 0·6324 gram CO_2 and 0·2762 gram H_2O.

	Required for	Found.		
	C_8H_{18}	*1*	*2*	*3*
C	84·20	84·35	84·61	84·33
H	15·79	15·12	15·28	15·01

The low percentages of hydrogen indicated the presence still of a small quantity of the hydrocarbon containing less hydrogen, perhaps, of a series C_nH_{2n}, although the main constituent seemed to be a member of the series C_nH_{2n+2}. For further purification, another portion of the same fraction was boiled for a long time with a mixture of nitric and sulphuric acids, and with sodium as long as a solid substance was formed, and until no colored residue was left after distillation. A combustion then gave 83·90 per cent. of carbon, and 16·10 per cent. of hydrogen, showing that the oil was then practically pure octane. This fraction is receiving careful attention with reference to the action of chlorine and the formation of its derivatives.

Between 120° and 128°, the distillates collected with some persistence, as shown by the following weights after the eleventh distillation:

	120°–121°	121°–122°	122°–123°	123°–124°	124°–125°	125°–126°	126–127°	127°–128°
Grams	85	70	80	60	30	30	70	60

The weights between 120° and 124° seemed to indicate the presence of definite bodies which should require larger quantities of the oils for longer distillation and study of their behavior toward chemical reagents. One hundred and ten grams collected after the twelfth distillation at 126°–128°, barometer 758 millimeters, and after careful purification in

the manner already described, the result of the vapor density determination corresponded to octane; found 4·24, required 3·95. The accumulation of such a large quantity of product within these limits shows the necessity of further examination of the distillate containing octanes. The fractions collected at 130°–142°, containing the xylols, will be considered later. At 145°–146°, after the twentieth distillation, fractions collected with much persistence near 145°, which evidently require further study to determine whether this indicates the presence of a definite compound:

	142°–143°	143°–144°	144°–145°	145°–146°	146°–147°	147°–148°
Grams	30	32	50	75	25	22

At the end of the tenth distillation, 160 grams collected at 149°–152°, of which a large portion distilled constant at 150°–151°, barometer 749 millimeters, and gave a vapor density required for nonane; found 4·56; required for C_9H_{20}, 4·43. Distillation of the portions above 160° will be continued. The results thus far obtained indicate that the series C_nH_{2n+2} is represented by the same hydrocarbons in the Canadian oil as have been found in Ohio and Pennsylvania oils, but the lower members of the series are evidently present in much smaller proportions than in either of the other oils. This should be understood to apply to oil from the Petrolia field. As elsewhere shown (*Proc. Amer. Acad.*, current volume), the oil from Oil Springs contains much more of the volatile constituents.

AROMATIC SERIES.

Series C_nH_{2n-6}.

Benzol.—In separating the members of the aromatic series, after the eighth distillation, 20 grams collected at 77°–79°, 15 grams at 79°–81°, and 30 grams at 81°–83°. These fractions were treated with nitric acid in the manner already described for the formation of nitrobenzol, distilling off the hydrocarbons not affected by the acid. The first fraction gave 2·8 per cent. of benzol, the second 4·4, and the third 4·14 per cent. This quantity of benzol corresponds, in the total weight of the fractions, to 3 grams, representing 0·0047 per cent. in the 64·5 kilos of crude oil first distilled. Scarcely

any benzol was found in the higher and lower fractions; the percentage is, perhaps, somewhat higher than is here represented, although considerably less than the amount contained in the Ohio oil. The nitrobenzol was recognized by conversion into aniline, which gave its characteristic reaction with furfurol.

Toluol.—After the eighth distillation the distillate between 107° and 109° amounted to 40 grams, at 109°–111° to 250 grams, and at 111°–113° to 50 grams. In treating these fractions for the formation of nitrotoluol, from 109°–111° a weight of nitro-product and unaffected hydrocarbon was obtained, equivalent to five per cent. of toluol from the fraction 107°–109° one per cent., and from the fraction 111°–113° one per cent., the higher and lower fractions giving no nitrotoluol. The total weight of toluol in the three fractions was, therefore, 3·4 grams, equivalent to 0·005 per cent. of the total weight of crude oil taken. As a proof of toluol the nitro-derivative was converted into toluidine, which gave characteristic color reactions.

Xylols.—As already explained, Schorlemmer obtained indications of the presence of benzol and its homologues in Canadian petroleum, and separated cumol in the form of the trinitro-derivative. Between 126°–143°, after the twentieth distillation, the following weights were obtained:

136°–137°	137°–138°	138°–139°	139°–140°	140°–141°	141°–142°	142°–143°
30	40	25	40	25	47	30

On account of the close proximity of the xylols in boiling points it would require longer distillation with large quantities of the oils to separate them completely. We, therefore, depended upon the formation of derivatives with properties sufficiently well characterized for conclusions concerning the xylols from which they were formed. In the fraction 137°–138°, p-xylol was tested for by heating a portion of the oil with nitric and sulphuric acid. The oil deposited, on standing, a crystalline product, which, after crystallization from alcohol, melted at 139°–140°, therefore corresponding to trinitro-p-xylol. After oxidation of another portion of the same oil with chromic acid, the solution was extracted with ether and the ether evaporated; the white powder that remained

sublimed without melting, and resembled, in its appearance and properties, terephthalic acid. The quantity of p-xylol was determined according to the method suggested by Levinstein, which consists in shaking the oil thirty minutes with concentrated sulphuric acid and noting the decrease in volume. The loss in volume corresponded to 10·77 per cent., representing other aromatic hydrocarbons. The oil remaining was then agitated with fuming sulphuric acid to dissolve p-xylol, the diminution in volume representing 9·02 per cent. In fraction 139°–140° m-xylol was determined by treating a portion of the oil with dilute nitric acid washing with caustic soda and distilling with steam, which carries over the m-xylol (Brüeckner, *Ber.*, **9**, 405). The loss in volume, 7·5 per cent., was noted, and the distillate agitated with concentrated sulphuric acid; the last diminution of volume represented 8·8 per cent. of metaxylol. In attempting to determine the presence of orthoxylol, and following closely methods which have been suggested for detecting this body in presence of the meta- and the para-compounds, the nitro-products and sulphonic acids separated resembled so closely the meta-derivatives that no conclusions could be reached as to orthoxylol. Evidently much larger quantities of these distillates and special methods of separation will be necessary.

Referring the weights of the xylol-nitro-products through the weights of the fractions to the original weight of crude oil, the quantity of paraxylol is 0·006 per cent., of metaxylol 0·005 per cent. Through the formation of sodium xylolsulphonate 0·009 per cent. of xylol was found in fraction 142°–143°, which should apparently be referred to the quantity of metaxylol. Evidently these results can be accepted as represented, only approximately the quantities of the xylols, but they doubtless represent the comparative quantities in the two oils under consideration. In the distillates between 130° and 140° there were indications of other aromatic hydrocarbons capable of forming nitro-products, but larger quantities of the oils will be needed for their separation.

SERIES C_nH_{2n}.

In examining the fraction 68°–69°, collected after the twelfth distillation, for hexahydrobenzol, it was carefully purified with alcoholic mercuric chloride, nitric acid, sulphuric acid, and boiling with sodium. A combustion then gave percentages of carbon and hydrogen required for hexane: carbon 83·45, required 83·71; hydrogen 15·99, required 16·28.

The fraction 97°–98° was purified in a similar manner, except with a mixture of nitric and sulphuric acids, which gave a nitro-compound heavier than water, equivalent to ten per cent. of the original oil. This nitro-compound dissolved readily in sodic hydrate with a red color and reprecipitated with acids. The purified oil gave percentages of carbon and hydrogen required for heptane: carbon 84·31, required 84·00; hydrogen 15·77, required 16·00.

This distillate, therefore, consisted chiefly of heptane, and it contained no hexahydrotoluol.

Hexahydroisoxylol, C_8H_{16}.—After treating with concentrated nitric and sulphuric acids the fraction 118°–119° of the sixteenth distillation, the acid was considerably colored from decomposition, and, on cooling, crystals formed, which were sparingly soluble in cold alcohol. When purified from hot alcohol this substance melted at 178°, the melting point of trinitroisoxylol. Hexahydroisoxylol was therefore present in this distillate, although only in small quantity. Determinations of carbon and hydrogen seemed to indicate still a small quantity of the hexahydro-compound, as shown by the low percentage of hydrogen, yet the principal constituent evidently belongs to the series C_nH_{2n+2}:

	Required for.		Found.		
	C_8H_{18}	C_8H_{16}	1.	2.	3.
C . . .	84·20	85·71	84·35	84·61	84·33
H . .	15·79	14·28	15·12	15·28	15·01

That this distillate consisted chiefly of octane was shown by the percentages of carbon and hydrogen after the thorough treatment with acids and sodium already described: carbon, 83·90; hydrogen, 16·10.

The larger percentage of hydrogen, now sufficiently close

to the composition required for C_8H_{18} showed that the hexahydroisoxylol had been removed.

Hexahydromesitylene has been identified in Caucasus petroleum by Markownikoff and Ogloblin (*Ber. der deutsch. chem. Gesellsch.*, **16**, 1873), and it is quite possible that it is also present in Canadian petroleum. We shall submit larger quantities of the distillates between 135° and 140° to careful examination to ascertain whether it is a constituent of Canadian oil.

The work now in progress includes an examination of the distillates between 0° and 9° for the butanes; the portions distilling between 118° and 130° for the octanes, and the portions above 150°. Work is also in progress in this laboratory on the distillates above 150° from Pennsylvania petroleum, and on petroleum from the Macksburg field, taken at different levels, including the Berea grit oil. The sulphur compounds in Ohio and Canadian oils, and the nitrogen and oxygen compounds in Ohio oil, are also receiving attention.

In the study of Ohio petroleum, I have received efficient aid from Mr. E. J. Hudson, and in the Canadian oil from Mr. W. H. King. I should also acknowledge my obligations to Messrs. W. G. King and W. O. Quayle, instructors in this laboratory, and to my assistants, Messrs. Little, Cleveland and Giessen. This work has been carried on with aid granted by the American Academy of Arts and Sciences, from the C. M. Warren Fund for chemical research.

AN APPARATUS FOR EXPERIMENTING WITH THE LAWS OF FLEXURE OF BEAMS.

BY PROF. JAMES L. GREENLEAF.

The theory of elasticity applied to the strain and stress of material is the basis of nearly all structural design.

It cannot be considered completely satisfactory, for a deeper insight into molecular physics, in certain particulars, leads investigators to feel that it is not a finality.

However, granting that it is even a crude rendering of deeper truths, the fact remains that it offers a reliable and practically satisfactory process to the engineer.

Any one who is at all sceptical regarding the truth of this theory, or has had his faith in it shaken by discussion, can readily satisfy himself of its reliability by simple experiment upon that phase of it relating to flexure. There are few instances in which the processes of the calculus, applied to physical laws, find a more pleasing and direct corroboration from practical experiment, than in the case of the flexure of beams.

The following description concerns a simple but effective apparatus that I have devised for experimentally testing certain flexure formulæ for beams under peculiar conditions of support. It was easily and cheaply made, and can be readily adapted to a wide range of conditions of support and loading of beams.

Any one who has had experience in teaching the laws of resistance of materials will appreciate the practical value of such an apparatus in the class-room. Let the student work out his formulæ in the case of restrained beams, for instance, and then check the calculation of reaction, bending moment and deflection by actual experiment. The mathematics will then cease to be a mere abstraction for him, and become a personal possession.

Such exercises are easily possible with the apparatus illustrated.

The construction will readily be understood from a study of the illustration.

The scales are laid off directly on the wood in inches and tenths, and the hundredths are estimated.

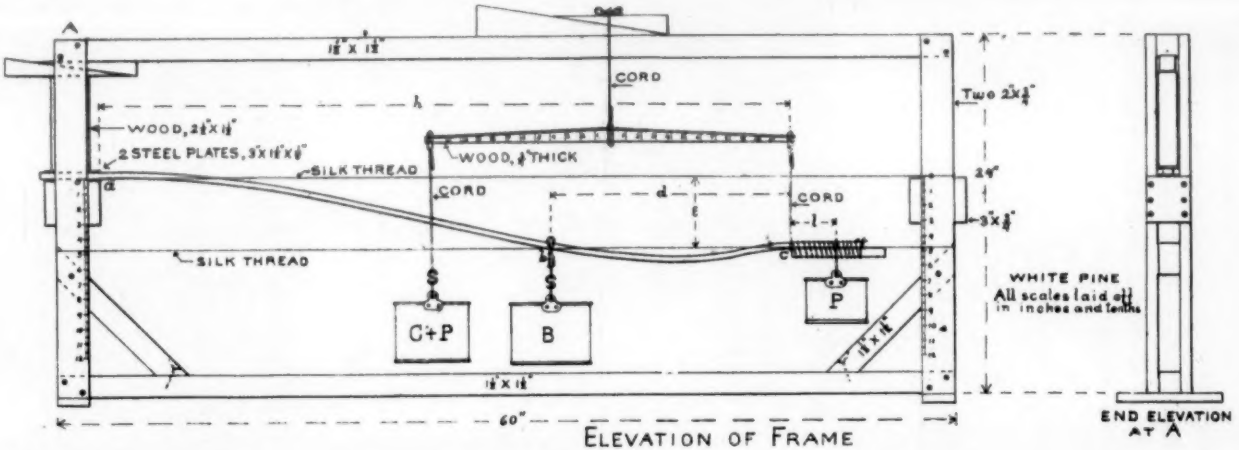
If more elaboration is desired, sliding verniers can be fitted to each of the two uprights, and the lower one of the silk threads be attached to them. Also, a small mirror can be weighted so as to hang vertically behind the threads, and then, by making the thread and its reflection coincide, the observer can insure a horizontal line of sight. In certain classes of experiments it would be more convenient to fasten a paper scale vertically on the side of the beam, and read off directly the deflection from the upper silk thread.

It is not at all difficult to obtain a considerable degree of sensitiveness in the apparatus, such that, with fifty pounds or more of weight in the pails, an increase of five or six of the finest bird-shot will cause a perceptible change in the deflection of the beam.

If the actual weights of the loads upon the beam are wanted, they had best be measured with a standard scale, but if simply the ratios of the loads are needed, they can be found accurately by the use of the wooden lever arm and the knife bearings.

As an example of the use of the apparatus, I will give the results of testing a beam under the conditions shown in the illustration. The beam is rigidly held at *a* by the steel plate, block and wedges, so that the tangent to the curve of deflection remains horizontal. It has a downward load at *b* and an upward one at *c*. Under the action of these two loads the beam deflects an amount, *e*. The condition is imposed that the points *b* and *c* shall be on the same horizontal line when the beam has settled down under the loads *B* and *C* (see *Fig. 2*).

Also the condition is imposed that the tangent to the curve of deflection at the end *c* shall be horizontal. This condition is readily met by first tying a short stiff strip to the end of the beam beyond *c*, so that it must remain straight beyond that point, and then hanging a load, *P*, upon it at any convenient short distance, *l*, from *c*. The amount



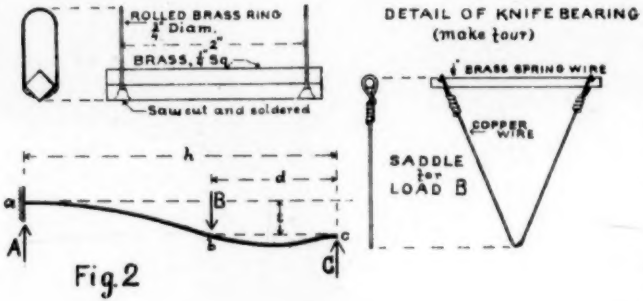


Fig. 2

FIG. 1.

APPARATUS FOR EXPERIMENTING UPON THE ELASTIC RESISTANCE OF BEAMS.

A large variety of experiments upon cantilevers, beams simply supported at both ends, restrained beams, and continuous beams can be made with this apparatus.

It is suitable for beams of wood or metal of moderate depth.

The weights consist of lead ingots and bird shot held in two quart tin pails.

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of P can be varied until the beam from c out occupies a horizontal line.

To give a suggestion of the practical bearing of the conditions assumed in this treatment of the beam, I may state that these are conditions to which columns in tall buildings or mill construction are sometimes subjected under wind pressure.

The formulæ applying to this case are as follows:

$A - B + C =$ zero.

$$C = \tfrac{1}{2}\, B\, \frac{(h-d)^2}{\tfrac{1}{2}\, h^2 - \tfrac{1}{3}\, h\, d}$$

or

$$C = \tfrac{1}{2}\, A\, \frac{(h-d)^2}{d\,(\tfrac{2}{3}\, h - \tfrac{1}{2}\, d)}$$

The origin of co-ordinates being taken at c and M_x denoting the bending moment at the distance x along the beam from c.

On the right of point b.

$$M_x = C\,(\tfrac{1}{3}\, d - x)$$

$$M_c = \tfrac{1}{3}\, C\, d$$

$$\frac{d\,y}{d\,x} = \frac{1}{E\,I}\, C\,(\tfrac{1}{3}\, x\, d - \tfrac{1}{2}\, x^2)$$

$$y = \frac{1}{E\,I}\, \frac{C}{6}\, (x^2\, d - x^3)$$

On the left of point b.

$$M_x = C\,(\tfrac{1}{3}\, d - x) + B\,(x - d)$$

$$\frac{d\,y}{d\,x} = \frac{1}{E\,I}\, \Big[\, (B - C)\, \tfrac{1}{2}\, (x^2 - h^2) + (B - \tfrac{1}{3}\, C)\, d\,(h - x)\, \Big]$$

$$y = \frac{1}{E\,I}\, \Big[(B - C)\, \tfrac{1}{6}\, \Big(x^3 - 3\, h^2\, (x - d) \Big) +$$

$$(3\, B - C)\, \frac{d}{6}\, \Big(- x^2 + 2\, h\, (x - d) \Big) + \frac{B}{3}\, d^3 \Big]$$

$$c = \frac{1}{E\,I}\, \Big[\, \frac{C}{3}\, h\, (h - d)^2 - \frac{B}{3}\, (h - d)^3\, \Big]$$

A comparison of figures 2 and 1 shows that the force B is represented by the weight of pail B. The upward force C at the theoretical end, c, of the beam, is represented by the weight of the pail $C + P$, minus the weight of pail P. (This is not strictly correct, but if l is made small, say one or two inches, the error can be disregarded. A correction can be entered if desired.)

In order to measure the ratio of C and B after an experiment has been made, detach the beam from the lever at c. Detach pail P from the beam, and hang it from the right hand arm of the lever at the same distance from the center as the pail $C + P$.

Then detach pail B from the beam and hang it with another knife bearing from the right-hand arm of the lever at such a distance out from the center that the system of weights suspended shall balance. (A small compensating weight equal to that of the knife bearing should be laid upon the left-hand arm of the lever at the same distance from the center on the position of load B.) Having obtained a balance the ratio of C to B equals the inverse ratio of the lever arms from the center to the loads $C + P$ and B.

As a refinement upon the above process it is important to make compensation for the weight of the beam.

This can be simply done with close approximation as follows: Before any weights are hung from the beam attach the beam to the lever at c, and hang a small weight (a small bottle loaded with shot is convenient) from the left-hand end of the lever, increasing the load until the end c of the beam is just raised to the upper silk thread.

This weight is to be retained as the compensating weight. When making an experiment on the beam place this compensating weight in pail $C + P$ as a part of the system of weights in balance. Then, when getting the ratio of C to B, and for computing the deflection remove the compensating weight from pail $C + P$.

I append a table of computed and experimental values that are extracted from the notes taken while making tests.

They show slight differences, and I believe these could

be largely reduced by exercising special care. The discrepancies in deflection are undoubtedly affected by the fact that the loads were only approximately determined in amount, although their ratios are practically precise. However, the comparatively small differences that occur in a wide range of experiments on varying ratios of h and d, with different-sized beams, and with loads varying from five to thirty pounds, show a decidedly close agreement between experiment and theory. This agreement, which is even closer in other series of experiments of a simpler nature that I have made, justifies the assertion that the theory of elasticity applied to material, within its elastic limit, unquestionably offers to the engineer a reliable and practically satisfactory process.

TABLE OF THEORETICAL AND EXPERIMENTAL DATA ON THE FLEXURE OF BEAMS SUBJECTED TO THE CONDITIONS SHOWN IN FIG. 2.

Number of Experiment.	Values of h and d. (Inches.)	Approximate Values of B and C. (Pounds.)	Ratios of B and C.			Deflection e, in Inches.		Character of Beam.
			Theory	Experiment.	Error of Experiment from Theory	Theory	Experiment.	
5	$h = 40$ $d = 8$	$B = 14{\cdot}4$ $C = 10{\cdot}6$	0·738	0·730	− ·008	0·99	1·38	Seasoned white pine, $2\frac{1}{16}'' \times \frac{3}{8}''$ section ($\frac{3}{8}''$ vert.) $E = 1{,}800\,000$ pounds. Compensated for weight of beam.
6	$h = 40$ $d = 10$	$B = 8{\cdot}4$ $C = 5{\cdot}0$	0·675	0·651	− ·024	0·69	0 62	
7	$h = 40$ $d = 10$	$B = 15{\cdot}5$ $C = 10{\cdot}5$	0·675	0·650	− ·025	1·10	1·13	
8	$h = 40$ $d = 10$	$B = 28{\cdot}0$ $C = 19{\cdot}0$	0·675	0·654	− ·021	1·96	1·92	
9	$h = 40$ $d = 10$	$B = 17{\cdot}9$ $C = 12{\cdot}1$	0·675	0·655	− ·020	1·30	0·93	
10	$h = 40$ $d = 15$	$B = 18{\cdot}4$ $C = 9{\cdot}6$	0·522	0·538	+ ·016	1·28	0·85	
11	$h = 40$ $d = 8$	$B = 25{\cdot}9$ $C = 19{\cdot}1$	0·738	0 714	− ·024	1·74	1·83	
12	$h = 40$ $d = 10$	$B = 7{\cdot}2$ $C = 4{\cdot}8$	0·675	0·668	− ·007	0 59	0·33	
13	$h = 40$ $d = 10$	$B = 21{\cdot}5$ $C = 14{\cdot}5$	0·675	0·658	− ·017	1·60	1·64	
14	$h = 40$ $d = 10$	$B = 7{\cdot}5$ $C = 5{\cdot}0$	0·675	0·651	− ·024	2·19	2·35	Seasoned white pine, $\frac{3}{4}'' \times \frac{23}{32}''$ section ($\frac{23}{32}''$ vert.) $E = 1{,}800{,}000$ pounds. Compensated for weight of beam.

THE THEORY OF THE AIR-LIFT PUMP.

BY ELMO G. HARRIS,
Professor of Engineering in the School of Mines of the University of Missouri.

The writer has no knowledge of any previous attempt at a mathematical analysis of the problem herein presented, except that of Professor W. H. Echols, which was read before the Philosophical Society of the University of Virginia, in 1891. Professor Echols made some interesting experiments in connection with his analysis, but unfortunately the data are not in such form as can be used in, or examined by, the formula herein obtained.

In *Engineering News*, of June 8, 1893, is an article on the "Air-Lift Pump," in which appears what seems to be a very complete account of what had been done up to that date. In that article may be found some discussion of the principles governing the action of this pump, but nothing more is established than the fact that the thing will and must act.

In this paper the writer has attempted an investigation of the principles involved, and an analysis of the action going on within the air-lift pump. The purpose of the investigation was to obtain a rational formula by which a pump could be designed intelligently, and on which experiment could be based.

It would have pleased the writer to have published with this first presentation of the subject the results of experiments testing the theory; but he has no means of carrying out such experiments.

An analysis of the action of the air-lift pump, and an investigation of the principles governing that action, can best be presented and investigated in several stages as follows:

(1) A vertical pipe, open at both ends, is partly immersed in a liquid. A quantity of gas is released within the pipe and below the surface of the liquid (*Fig. 1*). What effect will the gas have on the column of liquid; and what will be the action of the bubble of gas?

We will assume that the pipe is so large that capillary forces cannot control the action. Then the bubble will ascend. During the ascent the liquid above the bubble must pass by it in order to get below. Hence, the bubble cannot occupy the whole cross section of the pipe. In order to ascend the bubble must become elongated until the liquid can pass down. In order to pass down through the

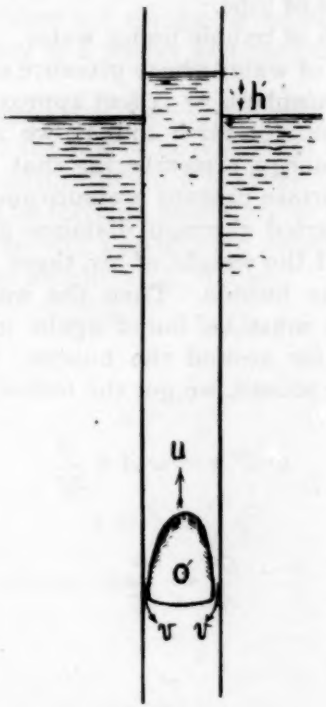

FIG. 1.

contraction formed by the bubble, the liquid must have a certain *absolute* velocity. The presence of this velocity is evidence of the existence of an unbalanced head somewhere above.

Let A = area of interior of pipe.
O' = volume of bubble, a variable.
O = volume of bubble under atmospheric pressure, a constant.

w = weight of a unit volume of water, or liquid.
Q = quantity of water passing down by bubble in a unit of time.
v = absolute velocity of water passing down by bubble.
u = absolute velocity of bubble ascending.
h' = difference of elevation of water inside and outside of pipe.
y = depth of bubble under water.
p = head of water whose pressure equals that of the atmosphere = 34 feet approximately.

To get an expression for v and h', we apply the law of conservation of energy, remembering that the buoyancy of the bubble is a certain upward pressure amounting to $w\,O'$; that pressure exerted through distance gives work; and that, if we neglect the weight of air, there is no energy in the motion of the bubble. Then the work done by the ascending bubble must be found again in the downward motion of the water around the bubble. Considering the work done in one second, we get the following equation:

$$w\,O'\,u = w\,A\,u\,\frac{v^2}{2g}$$

or

$$\frac{O'}{A} = \frac{v^2}{2g}$$

The term

$$\frac{v^2}{2g}$$

will be recognized as the equivalent of the head h' necessary to produce v. Hence

$$h' = \frac{O'}{A}$$

and

$$v = \sqrt{2\,g\,\frac{O'}{A}}$$

The same value for h' can be gotten from an equation of pressures. Thus

$$w\ O' = w\ h'\ A,$$

or

$$h' = \frac{O'}{A}$$

but this method does not recognize the existence of motion which is necessary to a proper conception of the action of the pump.

To get an expression for the upward velocity u of the bubble, we apply the law of physics, that forces are proportional to the velocities they can produce in a given mass in a given time. The force of buoyancy $w\ O'$ of the bubble produces in one second a downward velocity v in a mass of water having the weight $w\ Q$. Hence

$$w\ O' : v :: w\ Q : g$$

or

$$Q = \frac{O'\ g}{v}$$

Now

$$u = \frac{Q}{A} = \frac{O'\ g}{v\ A}$$

but it has been proven that

$$\frac{O'}{A} = \frac{v^2}{2\ g}$$

Therefore

$$u = \frac{v}{2}$$

This being established, it follows that the bubble, at its largest cross section, occupies half the area of the pipe. (See limitation, page 45.)

The writer attempted to work out the form of the bubble under the stated condition, but, on finding some of the terms in the eighth degree, he abandoned the attempt and contented himself with observing the form and motion in a

glass tube. It is an easy and exceedingly interesting experiment, and one recommended to those interested in this subject.

The time required for a bubble to ascend from a depth D to the top of the pipe can be found as follows:

$$d\,t = \frac{d\,y}{u} = \frac{d\,y}{\sqrt{\frac{g\,O'}{2\,A}}} = \left(\frac{2\,A}{g}\right)^{\frac{1}{2}} \frac{d\,y}{(O')^{\frac{1}{2}}}$$

Now, O' varies inversely as the pressure, and the pressure varies directly as the head of water. Hence

$$O' : O :: p : p + y$$

$$\therefore O' = O\,\frac{p}{p + y}$$

Substituting this value of O' we get

$$d\,t = \left(\frac{2\,A}{g\,O\,p}\right)^{\frac{1}{2}} (p + y)^{\frac{1}{2}}\,d\,y$$

Integrating between the limits D and zero, we get

$$T = \frac{2}{3}\left(\frac{2\,A}{g\,O\,p}\right)^{\frac{1}{2}} \left[(p + D)^{\frac{3}{2}} - p^{\frac{3}{2}}\right]$$

If we make $g = 32$ and $p = 34$, this becomes

$$T = \sqrt{\frac{A}{O}}\left[\cdot 028\,(D + 34)^{\frac{3}{2}} - 5\cdot 55\right]$$

An experimental determination of T will probably be the easiest test of the accuracy of the theory which is the basis of this paper. For reasons hereafter noted the writer recommends that in such a test the pipe be not less than six inches in diameter. Owing to friction the actual time is always longer than the computed time.

(2) Preliminary to a general investigation of the laws governing a pump operated by bubbles of air, we will take the special case illustrated by *Fig. 2*. Here the pipe terminates at the surface of the reservoir, and has only a single bubble liberated within it.

Now, in the absence of the standing head h', water will flow out at the top with a velocity v, and the rate of dis-

charge will be $A\,v$, but at the same time water will be escaping down by the bubble at the rate of

$$\frac{v\,A}{2}$$

The discharge at top is useful effect, the escape down by the bubble is lost energy. Hence it is apparent that two-

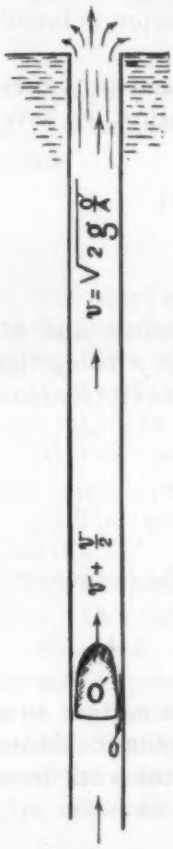

FIG. 2.

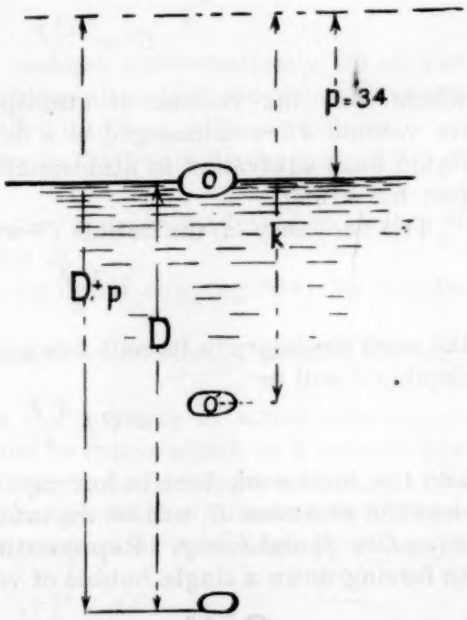

FIG. 3.

thirds of the work is utilized and one-third lost, or the efficiency is sixty-six per cent. This is interesting in itself, but it gives but little light on the practical problem. It should be carefully noted that u is now no longer absolute velocity. It is now the velocity of the bubble relative to

that of the water above or below. The downward velocity v of the water passing by the bubble is now relative also. It is really standing still at the largest cross section of the bubble.

(3) In order to proceed with the practical problem it is necessary to have an expression for the work done in forcing a given volume of air, or gas, down to a given depth under water, or other liquid. Such an expression is found as follows:

Observing the relation between volumes and pressures for a given mass of gas at constant temperature, we have (see *Fig. 3*):

$$Vol.\ O' : Vol.\ O :: p : k$$

Hence

$$O' = \frac{O\,p}{k}$$

where O is the volume at atmospheric pressure and O' its volume when submerged to a depth $k - p$, p being the liquid head equivalent to atmospheric pressure (thirty-four feet for water).

The buoyancy of the bubble O' will be

$$w\,\frac{O\,p}{k}$$

the work necessary to force it down through the elementary depth $d\,k$ will be

$$w\,O\,p\,\frac{d\,k}{k}$$

and the total work done in forcing O from the surface to a depth of emersion D, will be the integral between the limits $k\ (= D + p)$ and $k = p$. Representing by W_1 the work done in forcing down a single bubble of volume O, we have

$$W_1 = \int_p^{D+p} w\,O\,p\,\frac{d\,k}{k} = w\,O\,p\,log_e\left(\frac{D+p}{p}\right)$$

In this expression D is the static head on the bubble. Under working conditions the bubble would generally be released in a pipe in which the liquid is ascending with a cer-

tain velocity, which will be represented hereafter by V. Under these circumstances D must be replaced by

$$D - \frac{V^2}{2g}$$

Hence, the formula, in practical working, will generally be

$$W_1 = w\, O\, p \log_e \left(\frac{D - \frac{V^2}{2g} + p}{p} \right)$$

Now, if, instead of one bubble, we force down n bubbles in one second, the formula for work done per second becomes

$$W = w\, n\, O\, p \log_e \left(\frac{D - \frac{V^2}{2g} + p}{p} \right)$$

The next step is to account, mathematically, for all the work done by the n bubbles after they are released in the pipe. This will be divided into four parts, as follows:

(1) The kinetic energy in the liquid discharged at top of pipe. Call this K.

(2) The energy necessary to raise the liquid to the top of discharge pipe. Call this M.

(3) The energy lost by liquid slipping down by bubble. Call this L.

(4) The energy consumed by friction in passing through pipe. Call this F.

To get K, note that the quantity of water entering at bottom of pipe is $A\,V$, and to this is added, as it ascends the pipe, a quantity of air, which, as it escapes at atmospheric pressure, will, as it discharges, have a volume $n\,O$. Therefore, the velocity of the mixture of water and air at top of pipe will be

$$\frac{A\,V + n\,O}{A}$$

and the energy in the discharge will be

$$K = w\,A\,V \left[\frac{\left(\frac{A\,V + n\,O}{A} \right)^2}{2g} \right] = \frac{w\,V}{2g\,A} (n\,O + A\,V)^2$$

If h represent the height to which the pipe rises above the surface of the reservoir, then

$$M = w\ A\ V\ h$$

The absolutely correct formula for L is too complicated for use in practice. The writer has adopted an approximation which is sufficiently accurate for practical purposes.

It has been shown that the rate of loss of liquid from above to below one bubble is

$$v\ \frac{A}{2}$$

that is the bubble rises each second through

$$\frac{v}{2}$$

without doing useful work. This loss is always going on whether useful work is being done or not. The loss of work represented by this rise of the bubble relative to the liquid is

$$w\ O'\ \frac{v}{2}$$

per second, and if the bubble remains in the pipe for T seconds, the total loss for one bubble will be

$$w\ O'\ \frac{v}{2}\ T$$

but, since there are n bubbles passing per second the total loss in one second for the combined action will be

$$L = w\ n\ O'\ \frac{v}{2}\ T$$

If H represent the height of discharge above point of air inlet, and R represent the mean rate of ascent of a bubble, then

$$T = \frac{H}{R}$$

Now, R will be composed of two parts. First, the mean velocity of the ascending water. Second, the relative motion

$$\frac{v}{2}$$

of the bubble to the water above or below it. The volume of the bubble at top of pipe is O. At the bottom its volume is

$$\frac{O\,p}{D-\frac{V^2}{2g}+p}$$

since its volume varies inversely as the pressure. Hence, the mean volume of the $n\,O$ bubbles is

$$\frac{n\,O}{2}\left(1+\frac{p}{D-\frac{V^2}{2g}+p}\right)$$

Therefore,

$$R=V+\frac{n\,O}{2\,A}\left(1+\frac{p}{D-\frac{V^2}{2g}+p}\right)+\frac{v}{2}$$

Putting these values in the above expression for L it becomes

$$L=\frac{w\,n\,O'\,v\,H}{2\left[V+\frac{n\,O}{2\,A}\left(1+\frac{p}{D-\frac{V^2}{2g}+p}\right)+\frac{v}{2}\right]}$$

In getting this expression O' has been treated as a constant, while in reality it varies inversely as the pressure, and therefore changes at every stage of its ascent. It must also be noted that

$$v=8\sqrt{\frac{O'}{A}}$$

For an approximation O' will be assumed constant and equal to the mean value between top and bottom, that is

$$O'=\frac{O}{2}\left(1+\frac{p}{D-\frac{V^2}{2g}+p}\right)$$

To simplify the formula we will put

$$\frac{p}{D-\frac{V^2}{2g}+p}=C$$

Then

$$L = \frac{w\, n\, O\, v\, H\,(1 + C)}{4\left[\, V + \frac{n\, O}{2\, A}\,(1 + C) + \frac{v}{2}\right]}$$

To establish an expression for loss from friction we will work from the accepted formula, viz.:

Loss by friction = $w\, Q \times$ coefficient of friction

$$\times \frac{\text{length of pipe} \times \text{square of velocity}}{\text{diameter of pipe} \times 2\, g}$$

in which the coefficient of friction will be taken as ·02, and the velocity will be taken as the mean already used, that is

$$V + \frac{n\, O}{2\, A}\,(1 + C)$$

Inserting these and reducing we get

$$F = w\ {\cdot}0003\ H\ V\ \sqrt{A}\left[V + \frac{n\, O}{2\, A}\,(1 + C)\right]^2$$

Now, by the law of conservation of energy

$$W = K + M + L + F$$

or

$$w\, p\, n\, O\, \log\frac{1}{C} = \frac{w\, V}{2\, g\, A}\,(A\, V + n\, O)^2$$

$$+ w\, A\, V\, h + \frac{w\, n\, O\, v\, H\,(1 + C)}{4\left[V + \frac{n\, O}{2\, A}\,(1 + C) + \frac{v}{2}\right]}$$

$$+ w\ {\cdot}0003\ H\ V\ \sqrt{A}\left[V + \frac{n\, O}{2\, A}\,(1 + C)\right]^2$$

A solution of this equation by the regular methods of algebra, would be too difficult for practice, but fortunately the conditions are such that a solution can be readily reached by a tentative method as follows: Cancel w and treat the last two terms of the second member temporarily as a constant, representing them for simplicity by $l + f$.

Now, the equation will be a quadratic in $n\,O$. Putting $g = 32$, and $p = 34$, the value of $n\,O$ becomes

$$n\,O = \pm \sqrt{\left(A\,V - \frac{1088\,A\,\log\frac{1}{C}}{V}\right)^2 - \left(A^2\,V^2 + 64\,A^2\,h + \frac{64\,A\,(l+f)}{V}\right)} + \frac{1088\,A\,\log\frac{1}{C}}{V} - AV$$

the (—) sign to be taken.

Note that in the analysis it has been necessary to consider n and O separately. Hereafter the product $n\,O$ will be treated singly.

The data from which engineers will usually have to work will be numerical values of A, D, h and V. For a first approximation to $n\,O$ when h is greater than one-tenth of D, l may be taken as $\frac{1}{3}\,(A\,V\,h)$ and f not less than $\cdot 0003\,H\,V^3\sqrt{A}$. Insert these in the formula and solve for an approximate value of $n\,O$; insert this in the expressions for l and f and take out more accurate values of l and f; with these work out more accurate value of $n\,O$, etc. The second or third approximation will be found sufficiently close. Indeed, except for experimental investigation the first will generally suffice.

In computing l, v must be taken equal to

$$8\sqrt{\frac{O'}{A}}$$

O' will be difficult to measure and to control. If

$$O' = \frac{A}{4}$$

then $v = 4$, which would probably make a good working condition.

If the problem should be a given value of $n\,O$ from which to get V, it would be practically indeterminate except from a table giving values of $n\,O$ and V for all practical values of $A\,h$ and D.

RECAPITULATION.

Let A = area of pipe.

D = depth of immersion of point where air is admitted.

h = height of point of discharge above free surface of water.

$H = D + h$.

O = volume of a single bubble at atmospheric pressure.

n = number of bubbles admitted per second.

V = velocity of water in pipe below point of air admission.

$v = 8\sqrt{\frac{O'}{A}}$, (may be taken as 4 until more definitely determined by experiment).

$$C = \frac{34}{D - \frac{V^2}{2g} + 34}$$

$log \frac{1}{C}$ = Naperian (or hyperbolic) logarithm of $\frac{1}{C}$

= common logarithm of $\frac{1}{C} \times 2{\cdot}3$ approximately.

$$l = \frac{n\,O\,v\,H\,(1 + C)}{4\left[V + \frac{n\,O}{2\,A}(1 + C) + \frac{v}{2}\right]}$$

$$f = 0{\cdot}0003\,H\,V\sqrt{A}\left[V + \frac{n\,O}{2\,A}(1 + C)\right]^2$$

$$n\,O = -\sqrt{\left(A\,V - \frac{1088\,A\,log\,\frac{1}{C}}{V}\right)^2 - \left[A^2\,V^2 + 64\,A^2\,h + \frac{64\,A\,(l + f)}{V}\right]} + \frac{1088\,A\,log\,\frac{1}{C}}{V} - A\,V \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (III)$$

W = work delivered per second in foot pounds

$$= w\, n\, O\, p \log \frac{1}{C} = 2116\, n\, O \log \frac{1}{C}$$

$$E = \text{efficiency} = \frac{h\, A\, V}{34\, n\, O \log \frac{1}{C}}.$$

In order that equation (III) may be thoroughly understood and intelligently used, the following discussion is essential:

(1) The equation ceases to apply when $A\, V = n\, O$. For, on the assumption that the bubble occupies one-half of the area of the pipe, there would, at this limit, be a continuous column of air and a continuous column of water, each occupying half the area of the pipe—a condition obviously absurd. If h be taken as zero in equation (III), the roots become imaginary when $A\, V = n\, O$. In practice the limit will be reached sooner. After the limit is reached the outflow will probably become intermittent and the pressure in the air receiver irregular.

(2) Concerning the size of the bubble:

The law established on page 35 will not hold, or rather it gives way to another, when the size of the bubble is so small that the surface tension in the liquid, which tends to compress the bubble into a sphere, becomes stronger than those forces tending to draw it out until its area of cross section is one-half that of the pipe. By examining the expression for loss of work due to slip,

$$L = \frac{w\, n\, O\, v\, H\, (1 + C)}{4\left[V + \frac{n\, O}{2\, A}(1 + C) + \frac{v}{2}\right]}$$

it will be seen that this loss varies almost directly as v, and since

$$v = 8\sqrt{\frac{O'}{A}}$$

we must decrease O' in order to decrease L, until the limit is reached below which O' will not occupy half the area of the pipe. The effect of bringing the bubble below this

limit will probably be a loss of energy caused by whirls and contortions of the bubble which must create irregular currents and vortices within the pipe—such action as we always see when a bubble rises in a pond or large vessel. When the bubble is confined in a pipe of proper dimensions, its motion is perfectly regular. The writer ventures to pre-

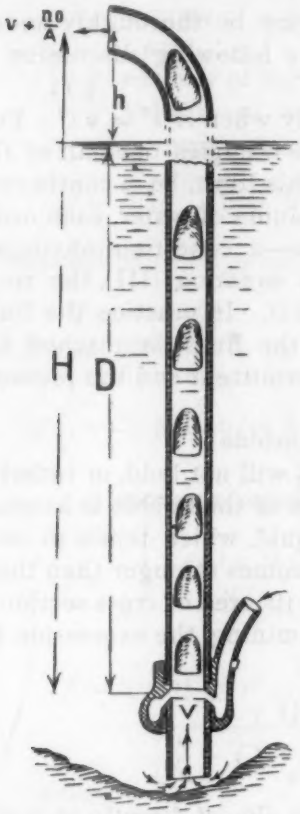

FIG. 4.

FIG. 5.

dict that the best results will be had when the volume of the individual bubble is just large enough to occupy half the area of the pipe. An expression for this volume in terms of the area of the pipe has not been found. It will be difficult to establish either by calculation or by experiment.

On the other hand, as the bubble increases, there seems

to be no limit if the bubble is allowed time to adjust itself to the forces about it, unless an exception be made of the case of a comparatively large bubble in a small pipe. Here surface tension tends to compress the bubble to a sphere, thereby causing it to fill more than half the area of the pipe.

(3) The loss due to friction is in no way peculiar to this method of raising liquid, and, if we wish to investigate results exclusive of friction, f can be omitted. The loss is known to vary approximately as the square of the velocity. The only way to reduce this loss is to use as large and as smooth a pipe as possible.

In the writer's opinion the apparatus best suited for carrying out the principles set forth in this article should be about as shown in *Fig. 5* or *Fig. 6*. *Fig. 5* shows the simplest conceivable form, and needs no explanation. *Fig. 6* would be more durable. It has also the advantage of being adjustable, the piece *n* being arranged to screw in or out, thereby closing or opening the circular slot through which air escapes. In both these designs the one great advantage of this style of pump is carefully guarded; that is, that it can act without an obstruction or contraction anywhere within the main pipe. It is by virtue of this that the pump is entitled to, and will hold, a place in the future. By this it is pre-eminently suited for a great variety of dredging processes. The writer first undertook this investigation with the intention of utilizing the device in the various dredging operations necessary in connection with the laying of submerged foundations. Suspended to a derrick and having a flexible air pipe, the air lift pump can be readily applied anywhere within the field of the derrick, and in very contracted spaces. For similar reasons it may be applied with advantage in placer mining in rivers and lakes. As a means of lifting sewage it seems to have everything in its favor. It has already been applied with good results for producing or increasing the flow from deep wells. It has also found a good field in elevating corrosive chemicals and hot liquids.

As a pump for raising liquid to great heights it will not be a success, for, in order to get good results, the depth of submersion must be greater than the lift.

In all that has preceded, it has been supposed that the air enters the pipe above its lower extremity, and without obstructing the pipe, as illustrated by *Figs. 5* and *6*. Hence the formulæ here given are inapplicable to some of the designs now in use. For instance, *Fig. 7* shows the design used at De Kalb, Ill.* Here the obstructions in the main pipe are very serious. There seems to be no good reason for attaching a reducer to the air pipe, nor for turning the nozzle up. Better results would probably have been gotten if both had been omitted.

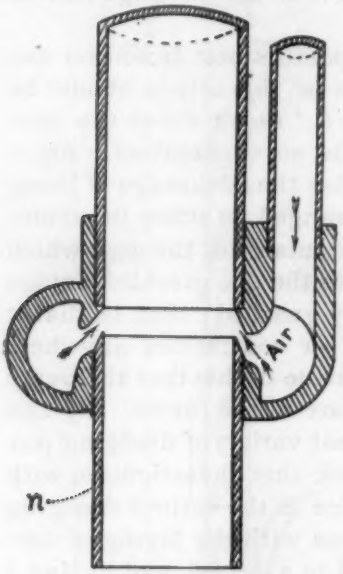

FIG. 6.

FIG. 7.

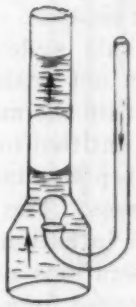

FIG. 8.

Fig. 8 is taken from a current advertisement of an air-lift pump. Here the air is released in a funnel attached to the lower end of the pipe. To this case the formulæ cannot apply unless we know what velocity exists in the water at the point where the air escapes. If this can be determined, the formula for work can be modified accordingly.

If the air escapes in still water, and then rises into the pipe, the formula will be simply

$$W = w\, n\, O\, p \log_e \left(\frac{D + p}{p}\right)$$

* See *Engineering News*, July 12, 1894.

Two patents have been granted by the United States, each, it is presumed, intended to cover the whole field of the air-lift pump.

In the first or older patent occurs the following claim:

"In the art of elevating water, the method of causing a column of water to ascend in a conductor by the weight of the external water, which consists of introducing a tube of the desired length at the required depth into the water to be elevated, and then injecting compressed air in the form of minute bubbles into the water at the lower end of the tube, thereby aërating the water, whereby a continuous stream is caused to flow upward to the point of discharge."

In a later patent the following is the first and chief claim:

"As an improvement in the art of elevating liquid, the process which consists in submerging a portion of an open-ended eduction pipe in the body of the liquid to be raised, and continuously introducing into the liquid within the lower part of the pipe a series of bubbles of a compressed gaseous fluid, containing enough of the fluid to expand immediately across the pipe and fill the same from side to side, forming pipe-fitting piston-like layers at or just above the point of their entrance into the pipe, whereby the column of liquid rises in the pipe after the forcing out of the liquid first standing in the latter is subdivided by the gaseous fluid into small portions before it reaches the level of the liquid outside of the pipe, and a continuously upward-flowing series of well-defined alternate layers of gaseous fluid and short layers of liquid is formed and forced up the pipe."

It will be seen that the first claim falls short of the best proportion for the bubbles, while the second overleaps it. The writer does not think the conditions set forth in the second claim can be realized except in small tubes under the condition pointed out on pages 45 *et seq.* Should this condition be found to hold in practice, l would be zero in equation (III). Otherwise the discussion would in no way be changed.

The slip of the bubble is capable of accurate determina-

tion by experiment as follows:* Cause the pipe to extend above the water so far that there will be no discharge of water. Then the loss from slip of the bubble must equal the work done or $L = W$. In equation (II) it will be remembered that we assumed the "slip" u to be

$$\frac{v}{2}$$

If then in (II) we put u for

$$\frac{v}{2},$$

and $V =$ zero, and equate it to W, we will get

$$\frac{w\, n\, O\, u\, H\,(1 + C)}{\frac{n\, O}{A}\,(1 + C) + 2\, u} = w\, n\, O\, p\, log\, \frac{1}{C}$$

Whence

$$u = \frac{n\, O\, p\, log \frac{1}{C}}{A\left[H\,(1 + C) - 2\, p\, log\, \frac{1}{C}\right]}$$

In the experiment, $n\, O$ and H will be measured, and C computed. Thus determined, u becomes an experimental coefficient, and the expression for l will be

$$l = \frac{n\, O\, u\, H\,(1 + C)}{\frac{n\, O}{A}\,(1 + C) + 2u}$$

The writer recommends that experiment be first directed along this line, and afterward to the determination of $(l + f)$, as a single experimental coefficient, from the equation

$$(f + l) = n\, O\, p\, log\, \frac{1}{C} - \frac{V}{2\, g\, A}\,(n\, O + A\, V)^2 - A\, V\, h$$

From data collected by the writer there seems no doubt that such pumps have been operated when the discharge of air exceeded the discharge of water, that is when $n\, O$ exceeded $A\, V$, but in all these cases the pipe was small or obstructed, and the data were indefinite.

* Suggested by Professor Echols in the paper already referred to.

The pressure of air necessary to start a pump is greater than that necessary to keep it in action when once started. That it must be so is clear when we reflect that the pressure in still water at a depth D is $w\,D$, but if the water be moving with a velocity V, the pressure is

$$w\left(D-\frac{V^2}{2g}\right)$$

Hence, the instant the discharge commences the pressure in the receiver will be reduced. This principle also accounts for the intermittent action which occurs under certain circumstances: Until a current is created, every bubble entering the pipe is under a pressure of $w\,D$; but the instant the discharge commences the pressure drops to

$$w\left(D-\frac{V^2}{2g}\right)$$

and all bubbles in the pipe expand suddenly, causing a mild degree of explosion which may nearly empty the discharge pipe, thereby bringing the pressure on the air inlet orifice below

$$w\left(D-\frac{V^2}{2g}\right)$$

which is the pressure needed to maintain continued action, too much of the compressed air will escape, and, when the violent action is over, the store of compressed air will be practically exhausted and the water will have an opportunity to regain its full static head D against the escape of air. This completes one period of the action.

To prevent intermittent action the escape of air into the discharge pipe must be controlled. It should be throttled the instant the discharge of water commences. That intermittent action does not always occur is probably due to the effect of friction in the pipe conducting air to the point of admission. As this friction increases with the square of the velocity, it is evident that in long pipes of small cross section it will serve to some extent as a governor, tending to control the discharge of air.

The tables below show results by equation (III). In tables 1 to 6 inclusive, f has been purposely neglected in order to show the results of conditions peculiar to this kind of pump.

		h	l	f	$n\,O$	E	
Table 1.	$A = ½$ $D = 20$ $v = 2$ $V = 4$ $C = ·63$	0 4 10	0·26 2·2 5·3	— — —	0·05 0·71 1·73	— 0·72 0·74	
Table 2.	$A = ½$ $D = 20$ $v = 4$ $V = 8$ $C =$	0 4 10					
Table 3.	$A = ½$ $D = 100$ * $v = 2$ $V = 4$ $C = 0·25$	0 4 32	1·0 3·0 23·8	— — —	0·08 0·27 1·95	— 0·64 0·70	
Table 4.	$A = ½$ $D = 100$ * $v = 2$ $V = 16$ $C = 0·26$	0 4 32	3·6 7·0 28·9	— — —	0·96 1·94 9·68	— 0·36 0·68	$n\,O > A\,V$ ∴ out of limit.
Table 5.	$A = 1$ $D = 100$ $v = 2$ $V = 4$ $C = 0·254$	0 4 32	4·42 6·10 36·44	— — —	0·29 0·54 3·66	— 0·63 0·75	
Table 6.	$A = 1$ $D = 100$ $v = 2$ $V = 16$ $C = 0·261$	0 4 32	6·60 11·33 72·00	— — —	1·68 3·33 16·91	— 0·42 0·66	$n\,O > A\,V$

		h	l	f	$n\,O$	E	
Table 7.	$A = 0·196$ ($d_1 = 3''$) $D = 100$ $v = 4$ $V = 4$ $C = 0·246$	0 4 8 16 23	0·6 3·2 5·3 9·42	0·8 1·0 1·27 1·74	0·03 0·16 0·28 0·52	— 0·42 0·47 0·52	
Table 8.	$A = 0·196$ $D = 100$ $v = 4$ $V = 8$ $C = 0·255$	0 4 8	3·26 6·74 9·19	7·92 10·40 12·55	0·30 0·59 0·86	— 0·24 0·33	
Table 9.	$A = 1$ $D = 40$ $v = 4$ $V = 4$ $C = 0·46$	0 4 10 13	1·71 11·29 25·20	1·80 2·49 3·86	0·18 1·20 2·74	— 0·50 0·55	

CELLULOSE PROTECTION FOR WAR VESSELS AND FOR THE MERCHANT MARINE.*

By B. P. Wiltberger.

While it has been proved that the present system of subdivision into a number of water-tight compartments, which has been adopted by all the large steamship lines, is a great step towards security, there are occasional instances where large vessels have been sunk notwithstanding this precaution. Absolute buoyancy can only be attained by cellulose protection, and, in the near future, all passenger steamers will be obliged to follow the path adopted by our men-of-war in that direction.

If, by means of a wall or belt of cellulose, protection is insured against the devastating effect of an explosive projectile passing entirely through the belt, how much stronger may be our faith that this same protection will be efficient, when, instead of such an engine of destruction, we have only to withstand the shock of wreckage, or rocks, or icebergs which smash, crack or break, but do not pass entirely through?

There are navigation laws requiring vessels to provide themselves with signals, fog horns, and the most powerful steering gear, to reduce speed and to follow the rules of the road in fog and storm. But, whether or not they conform to these requirements, the steamers provided with cellulose (in virtue of their absolute unsinkability) will have nothing to fear from the blows received from other vessels, from reefs forgotten by the chart-makers, or from icebergs so prevalent at certain seasons of the year.

Our government has adopted the cellulose system on all its latest warships, and it is said to be the intention of the Navy Department to coffer-dam *all* the warships with cellulose in the near future.

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* Abstract of a paper read at the stated meeting of the Institute, February 20, 1895.

Another new invention, by which leaks in vessels can instantly and permanently be closed, is the apparatus called "Colomes Leak Arrester." This invention I purpose now to show you in operation, and will be clearly explained by

FIG. 1.—Position of man in the act of inserting the arrester. A jagged hole four inches in diameter, with a water pressure of four feet.

the accompanying pictures. You will observe how easily the apparatus can be handled by reason of its lightness, and how quickly it can be applied.

The moral effect of having so simple a means of stopping leaks on board a vessel makes it imperative upon those

responsible for the lives of passengers to investigate this new system in which cellulose (from its yielding nature and wonderful qualities of filling up any sinuosity, burred or jagged parts of the orifice) plays a most important role.

FIG. 2.—The pick end has just fallen across the hole, and the inflow of water is partially checked. The man is placing the cellulose bag, washer and nut at the same time, and can now work without getting wet.

The striking results of previous experiments made, have induced the United States, France, and other governments, to include these leak arresters in the lists of outfits for their men-of-war.

SANITARY ENGINEERING.

By Wm. Paul Gerhard, C.E., Consulting Engineer for Sanitary Works; Mem. Amer. Public Health Association; Amer. Forestry Association; German Samaritan Society; Corresp. Mem. Amer. Inst. of Architects; Honorary Consulting Sanitary Engineer to the Department of Health of the City of Brooklyn, N. Y., etc.

Continued from vol. cxxxix, p. 475.

STREET PAVEMENTS.

All roads and streets serve for purposes of intercommunication and traffic; city streets, however, are planned with the further object of providing light and air to the adjacent houses, and, incidentally, are utilized as receptacles for a network of underground pipes, conduits and wires which afford drainage and sewerage facilities and furnish water, gas, heat, light, steam and electric power, etc., to the buildings. When we demand—even of our country roads—that they should not be dusty in dry weather, nor muddy and impassable in wet seasons, it is obvious that city streets, in which our habitations, offices and places of work are located, should be subject to much stricter requirements. We are, as far as this paper is concerned, interested chiefly in the sanitary aspects of street construction or the paving of its surface. The essential requirements of a good city street pavement are quick surface drainage, good foundations, impermeability and hardness of surface, avoidance of slipperiness, least resistance to traffic, cleanliness and noiselessness. Impermeability and noiselessness are the chief desiderata, from a sanitary point of view. There is plenty of medical testimony available tending to prove that the ceaseless noise, from early morning till late at night, due to vehicles passing over rough stone pavements, affects the nervous system and reduces the duration of life.

A street surface should be as water-tight as possible, to prevent a downward soakage into the ground of liquids, or the retention of filth in the joints and cracks of the paving stones. The street surface should drain off quickly, and

there must be no depressions or inequalities where water can stagnate and become offensive. A street pavement should not be slippery, as this not only causes horses to fall, but is equally dangerous to life and limb of pedestrians. Cleanliness of pavements is essential to prevent dangerous exhalations and illness due to polluted air. Finally, paved streets should be noiseless, for the continuous jarring and rumbling of heavy vehicles, the shaking of the foundations and the accompanying vibrations of window panes, doubtless affect the nerves of town-dwellers, disturb sleep, aggravate the suffering and retard the recovery of the sick.

For these and similar reasons the selection and construction of a good street pavement is a sanitary problem of much importance. Leaving out of consideration some kind of pavements which are not used to any great extent, the choice lies between macadam, wood, cobblestone, granite block and asphalt pavements.

Macadamized roads are not well suited for city pavements. Under a heavy street traffic the broken stones—particularly if the softer limestones are used—are quickly ground to powder, causing clouds of disease-breeding and irritating dust in dry weather, while in wet weather the dust is quickly changed into the worst kind of soft mud. The surface of macadamized roads wears out very quickly, and almost the only advantages worth mentioning are that such roads are noiseless, and that they afford a firm footing for horses.

Wooden pavements have formerly been employed, to a large extent, in American cities, but, of recent years, they have been given up, partly, no doubt, on account of the growing scarcity of timber, due to the barbarous destruction of our forests. From a hygienic point of view, wooden pavements, unless the blocks are impregnated to prevent decay, offer several important objections. In the first place, wood absorbs not only dampness, but likewise putrefying matter, and exhales bad odors, and, being alternately wet and dry, the surface soon rots. It is a well-known fact that decaying wood is detrimental to health. Wooden pavements, on account of their elasticity, are more noiseless

than stone pavements, but they are expensive to maintain, and soon their surface becomes quite unequal, except when the precaution is taken to lay the blocks on a concrete or sand foundation.

Cobblestone pavements are of a very inferior character, on account of the uneven surface, due to absence of proper foundation and the rough joints and numerous pockets, due to the irregularity of the stones. The joints of such pavements soon fill up with putrefying street filth and create obnoxious odors. Such pavements are very difficult to maintain in a clean condition, and, taken altogether, they are unfit for the thoroughfares of large cities.

Granite pavement, if composed of stones of regular size, evenly laid, well bedded on a good concrete foundation, and with the joints carefully filled with sand or cement, or tar and gravel, is a good city pavement for heavy traffic. The stone blocks should not be too hard, as they otherwise become quite slippery from abrasion, and the evenness of the pavement is usually disturbed by the frequent tearing up required for underground pipe connections. The improved stone pavements, with well-filled joints, have the one disadvantage of causing increased vibration of buildings.

The best pavement, from a sanitary point of view, is, without doubt, the asphalt pavement, and it is destined to become the favorite pavement for streets with light traffic. It is water-tight and quite impermeable; it prevents soakage into the subsoil; it is free from the noxious odors so often found on pavements with joints; it is durable, smooth, and very readily cleaned; it renders all traffic noiseless, does not cause jarring or vibration of buildings, and creates no dust due to abrasion and wear. About its only disadvantage is its liability to become slippery when the pavement is damp or greasy, as during foggy weather, or where soft mud is carried to it from adjoining stone pavements, by horses' hoofs, pedestrians' shoes and carriage wheels. It is principally adapted to the residential parts of cities, where there is no heavy traffic; owing to its noiselessness it is also preferred in the neighborhood of courthouses, schools, hospitals, etc.

Other durable pavements are the vitrified paving blocks, the asphalt blocks and brick pavements, in the laying of which particular care should be given to the filling in of the joint spaces.

Footpaths and sidewalks are paved with flagstones, or with artificial stone, with bricks laid flat, or with asphalt, and these should also be laid so as to afford good drainage into the gutters, and must be constructed so as not to become slippery. Gutters must be constructed with care, to avoid leakage of storm-water into the subsoil and the cellars of houses.

I have already alluded to the fact that city streets serve also the purpose of receptacles for many pipe conduits. In our large cities the number of different pipe lines buried under the street surface is constantly growing. We have not only one or several street water mains, gas mains, sometimes separate mains for fuel gas and lighting gas, sewers for rain-water and house-wastes, and in the "separate" system two lines of sewers, but also electric light conduits, telegraph wires for commercial uses, for fire alarm system, and for police telegraph; telephone wires, pneumatic conduits for mail, parcel delivery and telegraph messages; electric or pneumatic conduits for synchronized clocks; compressed air mains, cables and trolley line wires, steam conduits, hot-water pipes, pipes for cooling purposes, and what not. At street intersections the network of pipes is particularly crowded, for here we find, in addition to the above, the sewer man-holes, the catch-basins, the shut-off valves for water and gas, and the man-holes on subways for electric and telegraph wires.

In order to avoid the endless tearing up of streets and pavements, and the incidental disturbance of traffic, caused by repairs or connections to the various conduits, it has been frequently suggested to build subways in the more important streets, and to place all the above-named complicated network of engineering conduits and pipes in the same. While this would, doubtless, tend to secure a more permanent street surface, it involves a very large outlay of money for construction, and the remedy suggested is by no

means free from objections. Some of the most experienced municipal engineers have been opposed to the construction of subways. Much may be said on both sides of the question, but it would lead us too far to discuss the subject in detail. It is doubtless true that the maintenance of a permanent street surface is rendered difficult owing to the continued and repeated breaking up of the pavement for connection of water, sewer, gas and electric conduits.

STREET CLEANING.

We have learned how necessary good street pavements are, not only from the traffic point of view, but more especially from a sanitary standpoint, for the maintenance of the health of a city. But the advantages of well-paved streets count for nothing if the pavements are not thoroughly cleaned at regular and frequent intervals.

Street cleaning in the widest sense of the term includes the sweeping of roadways, sidewalks and gutters, the collection and removal of the road dirt, the sprinkling of streets, the removal of snow, the cleaning and disinfection of public conveniences, the cleaning and flushing of sewer catch-basins, and the removal of house refuse. I shall leave the latter out of present consideration, as it will be referred to further on, when speaking of scavenging, and shall restrict my remarks to a discussion of street dirt. The maintenance of city streets, and the scientific administration of street-cleaning in large cities, require a great deal of engineering knowledge, practical skill and judgment, besides not a little executive ability. It is not often, however, that the matter is considered in this way. Many instances could be quoted where in municipal departments mere politicians are placed in charge of the street-cleaning bureau, no doubt because street cleaning, like the construction of a state capitol, often involves the employment of a large force of laborers whose political vote may thus be controlled at election time. Street cleaning may legitimately be considered one of the important problems of sanitary municipal engineering. Viewed in this light, the recent appointment, by a reform mayor, of an able civil and sanitary engineer of high reputation, to

the position of street-cleaning commissioner in the city of New York, cannot be too highly commended.

The quantity and the composition of street dirt depend upon a great many points, such as the character and material of the pavement, the width of the street, the density and class of population, the nature and size of the traffic, the condition of the weather, etc. Road detritus is composed chiefly of abraded particles of stone, wood, iron and shoe leather; gravel, sand or mud from the subsurface; the horse-dung and urine of animals, mixed together with house refuse, ashes, street and yard sweepings, more or less garbage, dead leaves and other vegetable matters. Some of this dirt, and particularly that of animal origin, becomes absorbed in the joints or cracks of ill-laid or ill-kept pavements, where it keeps the subsoil damp and contaminated, putrefies and causes noxious smells and disease-breeding emanations. A part of the street dirt is breathed directly into our lungs, or enters the alimentary canal, and may cause internal diseases. When the March winds blow, and in dry seasons generally, the dust and dirt of streets is wafted about in the air, becomes injurious to the eyes of pedestrians, and is driven or blown into our houses, where it soon settles on the skin and the clothes of persons, on furniture, draperies, curtains and carpets. To avoid this, windows are kept closed and thus the rooms of our houses do not receive the necessary change of air. The street dust is also highly injurious to tradesmen's and shopkeepers' goods. When wet the dirt is changed into street mud, which is destructive to people's clothing, shoes and to carriages. Muddy and greasy streets also become a source of trouble by being slippery, and causing on sidewalks, street-crossings and in the carriage ways, numerous accidents to life and limb, to men and horses. As a rule, street dirt or mud is particularly bad about public hack stands, on open squares, near hotels, theatres and railway stations. Regarding the comparative quantity of street dirt from different pavements, an English engineer is authority for the statement that one cartload of street mud is, on the average, removed from 344 square yards of macadam, from 500 square

yards of granite, from 1,666 square yards of wood and from 4,000 square yards of asphalt pavement.

It is well known that streets in a bad condition are an obstruction to traffic, and that they necessitate a waste of energy and tractive force. We are accustomed to consider muddy streets as an annoyance, and we condemn unclean streets principally on account of untidiness of appearance. Very few people, however, take into consideration that, owing to air and soil pollution, caused by accumulation of dirt and refuse matter and soakage of liquid impurities, there is a powerful influence on public health, which by far outweighs all other disadvantages. It is a fact that clean and well-kept streets cause a marked reduction in the death rate of large cities, particularly as regards malarial and pulmonary ailments. Children playing in unclean streets are more or less affected, being often much more susceptible than adults; the same is true of invalids, and people not in robust health. Sanitary science, therefore, requires that the street surfaces be impermeable and that all thoroughfares should be kept scrupulously clean. Near children's schools, near institutions, and near hospitals the streets should, for obvious reasons, be swept with particular care, and be arranged with a view to perfect drainage. In all advanced schemes for the ventilation of buildings the fact that street dirt is injurious to health is taken into consideration, by providing special means for screening and filtering the air supply from outdoors, or by washing out its impurities. Dirty and dusty streets exercise at all times indirectly a baneful influence upon the salubrity of habitations, because they prevent the free ventilation of living or sleeping apartments by the opening of windows.

We have yet much to learn from Continental cities, which are far ahead of ours in the matter of street cleaning. This fact is generally conceded by all Americans who have travelled with open eyes through Europe, and who have admired the tidy and well-kept streets of some of its capitals. It is a matter beyond comprehension to me how the mayor of a large American city, after returning from a trip to England and the Continent, could have stated, as the news-

papers reported, that, in the matter of street cleaning, American cities had nothing to learn from cities like Paris, London, Berlin or Vienna.

The work of street cleaning presents difficulties which are not easily surmounted, chiefly on account of the enormous quantities of street refuse to be removed daily. It is accomplished by scraping, sweeping, washing and flushing. The sweeping may be done by hand labor with brooms, or else by the use of special machinery. Owing to the greater rapidity with which work is done there is economy in using the best machinery, implements and tools available. Mechanical sweepers should displace hand labor, for street cleaning by hand is from three to six times as expensive as cleaning by the aid of machines. It is a curious fact that the first street-cleaning machine, devised by Sir Joseph Whitworth, was rejected "as interfering with the labor for poor people." Street sweeping should always be done without stirring up dust and dirt. Hence, water is needed in street-cleaning operations, and all streets should be sprinkled before sweeping.

Carelessness in street sweeping should not be tolerated. In all large cities, street cleaning should be preferably done at nighttime. The method of cleaning streets by washing the filth and dirt into the gutters and catch-basins, and thence into the street-sewers, cannot be approved, except in special instances, as it simply transfers the dirt from the street surface to the catch-basin and the sewer. Dry removal of street dirt in large, well-built, covered carts is much to be preferred. Horse-droppings on important thoroughfares should always be picked up at once and removed with brushes into handbags. The fact should be noted that the extensive application of steam and electricity to replace horse traction in surface roads tends to reduce the amount of organic street dirt. The ultimate disposal of the collected street refuse is another problem which may present difficulties in large cities with many miles of pavements.

REMOVAL OF ICE AND SNOW.

A problem which, in winter time, taxes the ingenuity of the engineer of a street-cleaning department to the utmost,

is the removal of a sudden fall of snow, particularly when the snow storm is accompanied by high winds, causing the snow to collect in drifts. The snow, accumulating on sidewalks and footpaths, must be swept off by the adjacent householders, and fines should be enforced for non-compliance with the city ordinances. The snow is best removed as soon as the storm subsides, for when hard-trodden the mass is more difficult to handle. Sidewalks in front of vacant lots or unoccupied houses should be, under all circumstances, included in the city regulations, and if their owners are negligent, the cleaning should be done by the city, and the cost assessed upon the property.

The removal of snow from the carriage way is difficult to accomplish when the fall is heavy. Few persons realize the enormous quantities to be removed. Street railroad companies, after using the snow-plough to clear their tracks, should, by city ordinance, be required to remove that portion which they pile up outside of the tracks.

The mode of disposing of the snow varies according to the location of a city. In districts which adjoin a river or canal, or a harbor, the snow may be dumped from the carts into the water. In some cases it is thrown into the sewer man-holes. Owing to the fact that snow from frequented thoroughfares is generally mixed with street mud and road scrapings, the former method is often objectionable, as it causes the harbor or water-course to silt up, and necessitates dredging, and the second method should only be adopted if the sewers are simultaneously flushed with large quantities of water, otherwise it leads to deposits of mud in the sewer inverts. Melting the snow by fires, or by steam jets has been tried, but it is a slow and expensive proceeding. The use of salt to hasten the melting of snow is quite objectionable, as it causes a deep slush, and should only be tolerated when the slush is at once swept into the street gutters. Salting sidewalks or car tracks is very objectionable, from a health point of view, as the mixture causes much cold dampness, ruins pedestrian's clothing and shoes, is injurious to horses' hoofs, and causes the feet to be severely chilled, inducing colds, pneumonia, or the grippe.

STREET SPRINKLING.

In summer time, and in dry weather generally, city streets should be sprinkled to cool the air in hot weather and to keep down the street dust, with its many annoyances and inconveniences. Street sprinkling is accomplished largely by means of watering-carts or vans, but sometimes hose jets are used, or the street is watered by means of perforated pipes on wheels, attached directly to the street hydrants. The latter method is particularly adapted to well-kept impermeable asphalt pavements. The beneficial effect of street sprinkling upon the air is very marked; the air is washed of impurities, it becomes refreshed, and a feeling of relief is experienced similar to that after a thunder shower. It is a mooted point whether street sprinkling should be done by the city from the general improvement fund, or by private firms or corporations paid by the property owners of streets. I cannot see why street sprinkling should not be looked upon as a part of the general street cleaning system. The general traffic and pedestrians are certainly benefited by it quite as much as the owners of the property bordering on the street. It has been suggested in seaboard towns to water the streets with sea water, and the matter seems well worth trying, as it reduces the demand made upon the general city water supply in periods of drought, and also because salt water keeps the street surface damp for a greater length of time.

CLEANSING FOOTWAYS AND SIDEWALKS—STREET CROSSINGS—GUTTERS.

The sidewalks of streets should be kept scrupulously neat and clean. All accumulation of mud should be avoided, because it tends to make the sidewalks slippery. In winter snow should be regularly removed, and when ice forms it should be covered by the householders with sand or ashes, to prevent accidents and to avoid damage suits.

All street crossings need the particular attention of the street cleaners. They should be cleaned, swept and the mud raked off, and during snowfalls they ought to receive

attention first, so as to re-establish the regular street traffic with as little delay as possible.

The maintenance of the street gutters is particularly important from a sanitary point of view. Filthy gutters in hot weather are a source of danger, and cause noxious odors. They should be daily swept and kept unobstructed, to secure a rapid drainage of the street surface; there should be no pools of stagnant, offensive liquids in the gutters; they should be kept impervious to avoid leakage into the subsoil or into cellars, and they should have a continuous grade to the nearest sewer inlet. After snowfalls, gutters and inlets of catch-basins must be kept clear, so that when a thaw occurs there will be no flooding, rendering street crossings impassable.

REMOVAL OF REFUSE—GARBAGE DISPOSAL—SCAVENGING.

While sewers are intended to remove from habitations all liquid and semi-liquid organic matters, the solid refuse of a city, of its houses and streets, comprising ashes, offal, garbage, house-sweepings and street refuse must be removed by cartage. Sir Robert Rawlinson, one of the foremost sanitary engineers of England, calls scavenging one of the important features of city sanitary engineering. In dealing with this problem distinction is often made between regular and special refuse. It would be tedious to you, doubtless, if I were to enter into the subject fully, enumerating at length what constitutes ordinary house refuse. I shall, therefore, merely state that all house refuse should be divided into two distinct kinds, viz.: garbage and ashes, the former largely organic, the latter inorganic masses.

Scavenging deals not only with house refuse, but also with street refuse, with stable, garden and trade refuse, with market refuse, builders' rubbish and with the mud accumulating in street catch-basins. House refuse, paper and litter, should never be deposited in the roadway, nor should any of it be thrown into sewer man-holes or catch-basins. Pending removal, house garbage and rubbish should be stored in dust-bins or in barrels and ash cans, and it is essential, and by no means difficult to enforce,

that separate vessels be provided by householders for the garbage or swill, and the ashes and sweepings. Large fixed receptacles for temporary retention are not as desirable as small portable pails or cans, except, possibly, for large tenement houses.

The garbage pails should be of non-absorbent material, and ash cans should not be of wood, but of iron, to avoid danger of fire from hot ashes. All receptacles should be provided with tight-fitting covers, so that when they are placed on the sidewalk near the curb just before the scavenging cart arrives, the ashes may not be scattered by the wind, and the swill and offal may not offend the senses of passers-by when exposed to the rays of a hot July sun. I cannot discuss the details of the removal, except to say that it should be done at regular hours at all times, and that garbage must be more frequently removed in summer than in winter, to avoid the emanations due to rapid decay.

The city should, of course, provide separate garbage and ash carts of solid construction and fitted with covers to avoid a street nuisance during transportation. In summer time householders may help to reduce the amount of offal to be disposed of by drying, carbonising and burning some of the house garbage in the kitchen range.

Regarding the ultimate disposal of city refuse, it is found by experience that much of it may be utilized, after sifting and separating the coarser from the finer materials. This sorting of the contents of ash and garbage barrels should never be permitted to be done in the streets. The city refuse dumps are the places to which ragpickers should be relegated. All dirt, as Lord Palmerston said, is merely "matter in the wrong place." While ashes, cinders and clinkers may be utilized for the filling up of sunken lots or for making river banks or roads and pathways, no garbage should be so used or mixed in any way with ashes. Horse droppings from streets are salable as manure, and some part of the house offal can be disposed of to farmers for like uses. But whatever cannot be utilized in some way, must be removed by rail or by water. In harbor towns, city refuse is taken in specially constructed hopper barges far out to sea,

and dumped into deep water. This mode of disposal is not always desirable or feasible, as it may lead to a defilement of the beaches and bathing resorts near the city. There is little doubt that destruction of garbage by the all-purifying element—fire—is one of the best, if not *the* best, method from a sanitary point of view. Various refuse cremators have been contrived, which are operated successfully without causing a nuisance by the smoke and gases from the furnace. The ashes resulting from cremation have some value as fertilizers, particularly where sewage sludge or nightsoil is mixed with the refuse.

The cleaning of earth closets, privies, ashpits, cesspools, vaults, and sewer catch-basins is also a part of the city scavenging, but it would lead me too far to discuss the same.

[*To be concluded.*]

REASONS FOR PREDICTING THE EXISTENCE OF ARGON.*

By C. J. Reed.

Berzelius, about a half a century ago, advanced the theory that a compound molecule is made up of atoms having opposite electrical polarities. This theory, in the form proposed by Berzelius, would not explain the substitution of an electro-negative for an electro-positive atom in a molecule, and the theory soon fell into disrepute.

About fifteen years ago Prof. Otis C. Johnson revived this theory in a modified and greatly improved form.

Professor Johnson first assumed that the algebraic sum of the affinities in a molecule is always zero. He then, by definition, makes oxygen an arbitrary standard of valence and polarity, by assuming that in combination it is always an electro-negative dyad. It follows that the valence and polarity of other elements with respect to oxygen is variable, and is determined in any particular compound by the rule

* Read at the meeting of the Chemical Section, May 21, 1895.

that the sum of the affinities in a molecule is zero. This theory, properly understsod, is not inconsistent with the substitution of electro-positive for electro-negative atoms in a compound molecule.

On this theory he found that oxidation is always equivalent to a change of affinity or bonds in one direction, and reduction to a change in the opposite direction, and that these two changes are always equal.

About ten years ago it was shown by the writer, in a paper read before the St. Louis Academy of Science, that a remarkable relation exists between the electro-chemical affinity and the atomic weight of an element. It was shown that the saturation valence is an equi-crescent rotary, or helical, function of atomic weight.

By the method of rectangular co-ordinates, points were located in a plane for each of the elements. Ordinates were taken proportional to the saturation valence—that is, to the maximum or minimum valence, or in some cases to the characteristic valence. Abscissas were taken proportional to the atomic weight. Electro-positive valence was measured upward, and electro-negative valence downward, from the axis of abscissas. *Fig. 1*, reproduced from the paper referred to above, shows this arrangement of the elements. The only changes that have been made from the original figure are the addition of a few elements since discovered, some slight changes in the atomic weights of a few elements, and the addition of the hypothetical element *A'*.

An inspection of this figure shows that nearly all of the elements fall on a peculiar series of double, equi-distant parallel lines, separated alternately by distances of one and sixteen units of atomic weight. This is particularly true of the elements of low atomic weight, scandium being the first notable exception. Beginning again at *Ge*, we find a remarkable tendency of the elements to follow the lines from *Ge* to *Mo*. From *Ru* to *Te* there is a diagonal movement from one pair of parallels to the next. From *Te* to *Ce* the arrangement is more regular. Between *Os* and *Bi* this regularity is again plainly recognizable.

Those elements which follow the general course of the

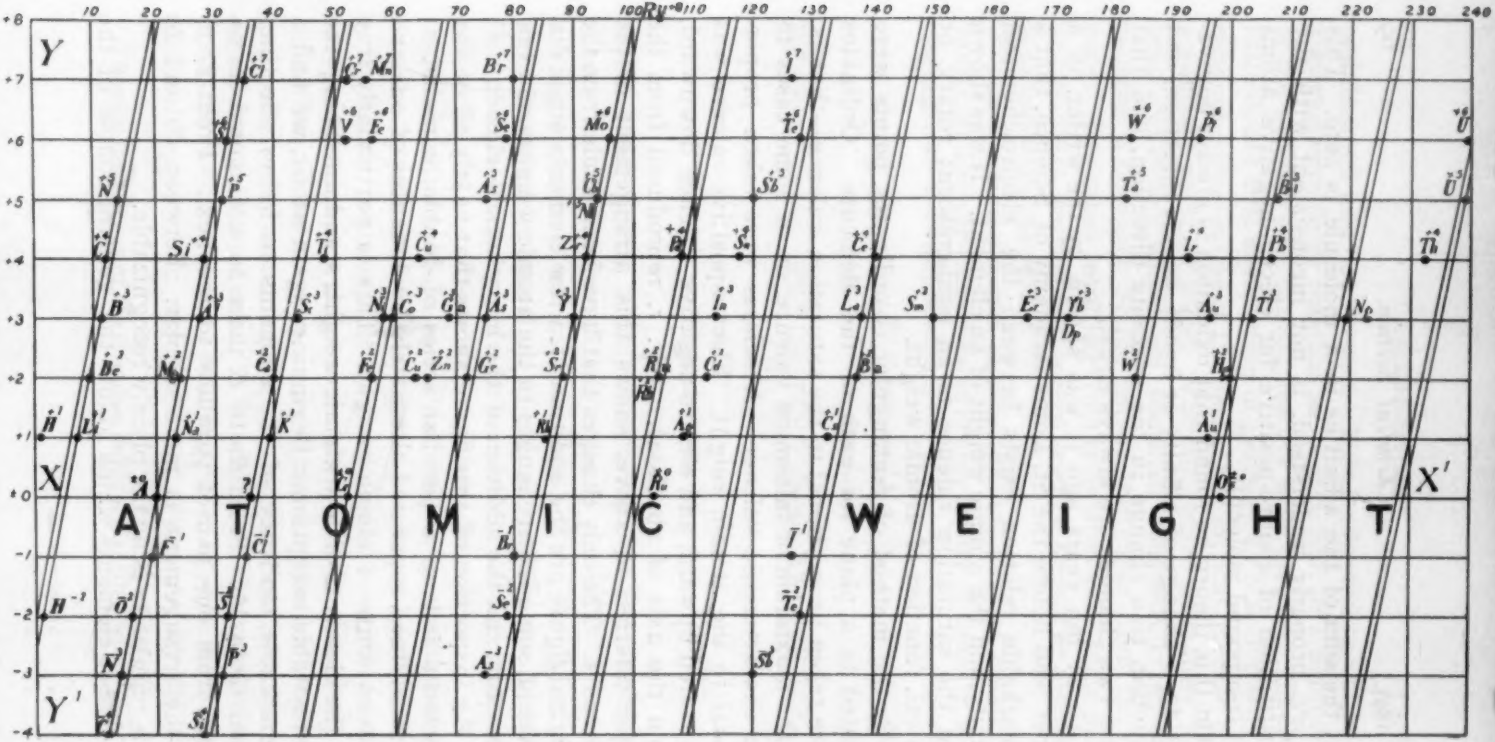


FIG. 1.—DIAGRAM SHOWING THE RELATION BETWEEN VALENCE AND ATOMIC WEIGHT.

parallels, without actually falling on the lines, generally deviate either towards the left or towards the vacant region.

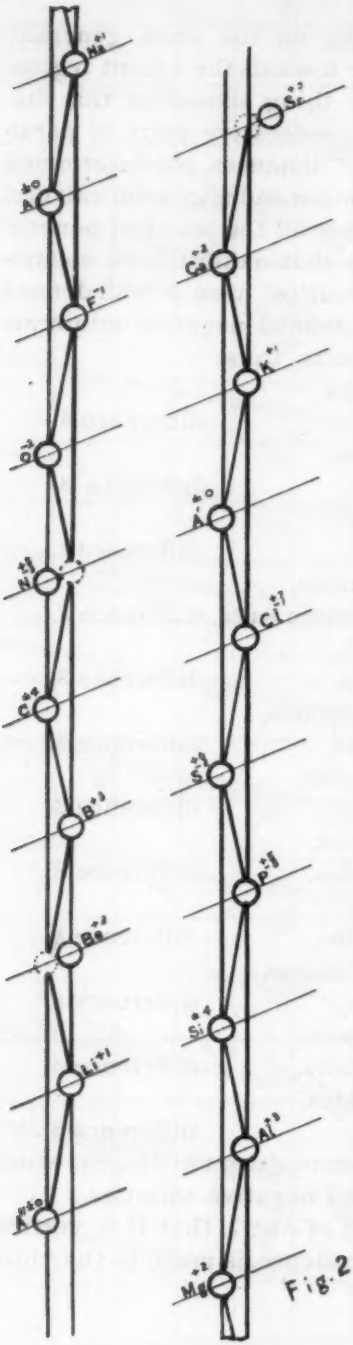
Perhaps the most remarkable thing shown on this diagram is the manner in which the successive pairs of parallels are linked together and their distances pre-determined by the connection between maximum and minimum valence.

It is a very remarkable fact that all the so-called non-metallic elements, that is, elements that exhibit both electro-positive and electro-negative affinities, have a well-defined positive maximum and a well-defined negative minimum valence, which differ by eight units, thus:

C is + 4 in CO_2 and carbonates,	
C is — 4 in H_4C,	difference 8.
N is + 5 in HNO_3 and nitrates,	
N is — 3 in H_3N,	difference 8.
Si is + 4 in SiO and silicates,	
Si is — 4 in H_4Si,	difference 8.
P is + 5 in HPO_3 and phosphates,	
P is — 3 in H_3P and phosphonium salts,	difference 8.
S is + 6 in SO_3 and sulphates,	
S is — 2 in H_2S and sulphides,	difference 8.
Cl is + 7 in $KClO_4$ and perchlorates,	
Cl is — 1 in HCl and chlorides,	difference 8.
As is + 5 in As_2O_5 and arsenates,	
As is — 3 in H_3As,	difference 8.
Se is + 6 in SeO_4 and selenates,	
Se is — 2 in H_2Se and selenides,	difference 8.
Br is + 7 in $HBrO_4$,	
Br is — 1 in HBr and bromides,	difference 8.
Sb is + 5 in Sb_2O_5 and antimonates,	
Sb is — 3 in H_3Sb,	difference 8.
Te is + 6 in TeO_3 and tellurates,	
Te is — 2 in H_2Te and tellurides,	difference 8.
I is + 7 in H_5IO_6 and periodates,	
I is — 1 in HI and iodides,	difference 8.

This includes all known elements, except hydrogen, which exhibit well-marked positive and negative affinities.

It will be seen, by inspection of *Fig. 1*, that if a vertical displacement of eight units of valence is made in the third



pair of lines it will bring the maximum and minimum values of Si, P, S and Cl into coincidence, and that the third pair of lines will then be a continuation of the second. The same effect is produced on all the lines, without any vertical displacement, by bending the plane into a cylinder having a circumference equal to eight units of valence. The parallels are thus all united into a double helix, the axis of abscissas forming an element of the surface of the cylinder. The axis of ordinates becomes a circle of the cylinder, and valence, now measured in angular measure, is directly proportional to atomic weight. The double helix becomes a sort of chain, on which the elements are arranged as shown in *Fig. 2*.

In this figure we find other striking analogies. With the exception of *Be* and *N*, the artiads are all on one line and the perissads all on the other. The alternate arrangement is extremely regular. Before the discovey of argon by Lord Rayleigh and Professor Ramsay, there was a vacancy at *A*, *Figs. 1* and *2*, requiring an element of atomic weight, 20; another at *A'*, requiring an element of atomic

weight, 36, and another at *A''*, requiring an element of atomic weight, 4. To conform with the analogies of the rest of the chain, these elements should have an affinity or valence of — 0 or + 8; that is, should be either incapable of combining with other elements, or else should have a maximum or characteristic valence of eight. In order to judge further of the properties of these unknown elements, we refer again to *Fig. 1.* We observe that the surface of the cylinder is divided longitudinally into eight equal parts, by the parallels of equal valence, the axis of atomic weights representing the valence + 0 and + 8; that the double helix, which we may call, for convenience, the locus of elements, cuts the axis of atomic weights at fifteen points, suggesting that there should be a group of fifteen elements having a valence of zero or eight, and that their atomic weights should be, respectively, 4, 20, 36, 52, 68, 84, 100, 116, 132, 148, 164, 180, 196, 212 and 228. But as all the known elements appear to be grouped together in certain regions of the cylinder, while the remaining portions are comparatively bare, we should naturally expect this to be true also of the new family of elements. The only members of this family, therefore, which we can reasonably expect to find in terrestrial matter are those occurring in the same regions. The only members of this group occurring in such regions are 1, 2, 3, 4, 6, 9 and 13, having atomic weights, respectively, 4, 20, 36, 52, 84, 132, 196; and possibly No. 7, having atomic weight, 100.

The most necessary of these are numbers 2, 3, 6 and 9, having atomic weights respectively, 20, 36, 84 and 132.

As to the properties of this new group of elements, little can be said, except in a very general way, owing to their peculiar position on the border line between the extremes of electro-positive and electro-negative affinity.

The following deductions, however, seem reasonable from the position of these elements with reference to that of known elements, as shown in *Fig. 2.*

The members of this group, when in the electro-negative state, should be more strongly electro-negative than the corresponding members of the sulphur group, and yet they should be without combining affinity.

The argon group are artiads, as they occupy a regular position on the artiad helix. Their characteristic valence is 0 or 8—that is, they should combine as octads, or else be incapable, or nearly incapable, of combining with other elements.

The possible number of these elements having atomic weights below 240 is fifteen, since the elemental locus cuts the axis of abscissas at that number of points. But only four, or at most six, of these are likely to be found in nature. Those most likely to be found are, in the order of their probability, argon, having an atomic weight, 20, which has lately been discovered by Lord Rayleigh and Professor Ramsay; *A'*, having atomic weight, 36; one having atomic weight, 84; and one having atomic weight, 132.

Like all electro-negative elements (except *C* and *Si* in the free state), they and their oxides and hydrides should be volatile.

As oxygen is more volatile than carbon, sulphur more volatile than silicon, fluorine (probably) more volatile than nitrogen, chlorine more volatile than phosphorus, bromine more volatile than arsenic, and iodine more volatile than antimony, we should expect from analogy that argon would be more volatile than oxygen; the element 36 more volatile than sulphur; the element 84 more volatile than selenium; and the element 132 more volatile than tellurium. In general, any member of the new group should be more volatile than the corresponding member of the sulphur group.

Argon and element 36 should, like most elements of low atomic weight, be comparatively abundant in nature, while elements 84 and 132 should be scarce, but not more rare than selenium and tellurium.

As the intensity of electro-negative affinity in any group diminishes with increase of atomic weight, and as electro-negative valence is not known in elements of higher atomic weight than 130, the element 196, if it exists, could not be expected to exhibit negative valence. This element should be a volatile metal, heavier and scarcer than gold and capa-

ble of easier reduction to the metallic state; also, it should be capable of forming an oxide of the formula RO_4, or a salt of the formula K_2RO_4. The volatile metal, osmium, agrees with the requirements of this element very closely, while ruthenium may possibly be the element 100.

Elements of this group will not combine easily with one another, and those of low atomic weight will probably not combine with any element, except possibly to form one or two unstable compounds which can exist only at low temperatures.

The lower members of this group should be decidedly non-metallic, like the lower members of all electro-negative groups.

The necessity for these elements impressed me very

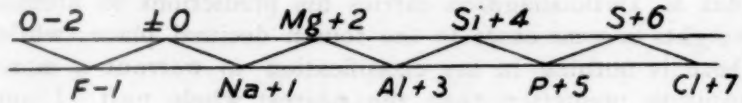


FIG. 3.

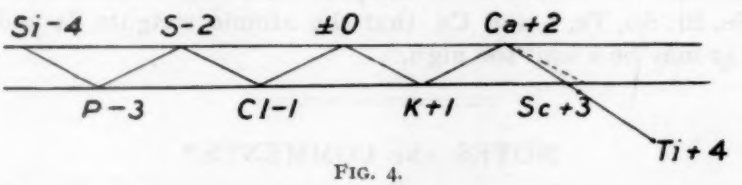


FIG. 4.

strongly at the time the paper above referred to was written, and in *Figs. 3* and *4* of that paper, reproduced here in facsimile, I actually marked the position of argon as an element having atomic weight, 20, and that of another element having atomic weight, 36, both being marked by the symbol ± 0.

In closing, it will probably be of interest to note that since the publication of the discovery of argon, M. DeBoisbaudran has stated (see *Chem. News*, **71**, 116) that he has found a classification of the elements that enables him to assume the existence of a family of elements, no member of which was known; that their atomic weights are, respectively, 20·0945, 36·40 ± 0·08, 84·01 ± 0·20, and 132·71 ± 0·15, assuming O = 16. He states that they should be non-

metallic, that the bodies, 20·0945 and 36·40 should be relatively abundant in nature, the other two rare.

"The atomicity of the new family should be even (octovalent), but its component elements should be devoid of the faculty of combining with other elements.

"The element 36·40 should be more volatile than sulphur and the element 20·0945 more volatile than oxygen. Lastly, the elements 84·01 and 132·71 should be, respectively, more volatile than selenium and tellurium."

As M. DeBoisbaudran neither gives the reasons for his deductions nor explains his classification, I am unable to state whether there is any similarity between his system and my own. His conclusions, it will be noticed, are remarkably similar to mine, the principal difference being that M. DeBoisbaudron carries his predictions on atomic weights in some cases to the fourth decimal place; while there is nothing in my classification to warrant a more accurate prediction than the nearest whole unit. I am inclined to believe from the position of the elements, As, Se, Br, Sb, Te, I, and Cs, that the atomic weights 84 and 132 may be a unit too high.

NOTES AND COMMENTS.*

AMERICAN TOOLS IN ENGLAND.

The Iron Age, in a recent impression, prints an interesting interview with the representative of a leading English firm of engineers and importers of American machinery, which has been engaged in the business for thirty years.

The following quotations from this source will doubtless be read with interest, viz.:

It appears to be, first and broadly, that high-grade tools, both special and standard, are in demand. Tools of poor design and showing poor workmanship are not wanted, and the attempt to introduce them has not proved successful. Users of machine tools in England have become convinced of the superiority of American makes of tools of certain descriptions. This refers particularly to the automatic and universal machines, such as automatic screw and bolt machines and universal grinders. These two are merely mentioned as an indication of the type of machines which find ready sale. The

* From the Secretary's monthly reports.

(g) Bituminous coal includes brown coal and lignite. The anthracite production is the total for Pennsylvania, Arkansas and Colorado.
(e) Estimated.
* Kilograms.

THE MINERAL PRODUCTION OF THE UNITED STATES—1893-1894.

The accompanying table, exhibiting the amounts and values of the various mineral products of the United States for the years 1893–1894, we are permitted to print by courtesy of Mr. R. P. Rothwell, editor, from advance sheets of "The Mineral Industry," vol. iii.

MINERAL PRODUCTION OF THE UNITED STATES, 1893 *and* 1894.

Compiled for THE MINERAL INDUSTRY, Vol. III.,
By Richard P. Rothwell, editor of "The Engineering and Mining Journal."

No.	Products.	Customary Measures.	1893. Quantity. Customary Measures.	1893. Quantity. Metric Tons.	1893. Value at Place of Production.	1894. Quantity. Customary Measures.	1894. Quantity. Metric Tons.	1894. Value at Place of Production.
	NON-METALLIC.							
	Abrasives—							
1	Corundum and emery	Short tons	1,747	1,585	$140,580	1,220	1,106	$109,500
2	Garnet	"	1,520	1,379	55,800	1,000	907	35,000
3	Grindstones	"	45,340	41,133	345,920	37,400	33,922	335,800
4	Millstones	"	155	141	2,359	297	269	4,447
5	Tripoli and infus. earth	"	1,351	1,226	25,625	1,802	1,634	36,687
6	Whetstones	"	1,903	1,726	89,550	1,735	1,574	84,450
7	Alum	"	96,000	87,093	2,880,000	72,000	65,304	2,160,000
8	Antimony ore	"	850	771	41,000	165	150	9,075
	Asbestos and Talc—							
9	Asbestos	"	120	109	6,000	250	227	3,750
10	Fibrous talc	"	36,500	33,113	337,625	39,600	35,917	396,000
11	Talc and soapstone	"	20,100	18,235	366,825	21,044	19,087	401,932
12	Asphalt	"	3,490	3,166	68,682	4,198	4,080	75,654
13	Bituminous rock	"	31,404	28,489	114,752	34,199	31,018	148,120
14	Barytes	"	25,632	24,161	133,160	23,758	21,548	95,032
15	Bauxite	Long tons	11,041	11,222	55,205	10,732	10,908	42,928
16	Borax	Pounds	9,199,000	4,173	689,925	13,140,589	5,962	919,841
17	Bromine	"	348,399	158	87,100	379,444	172	98,655
18	Cement, natural hydraulic	Bbls., 300 lbs.	7,445,950	1,013,238	5,010,958	7,895,259	1,074,179	4,397,407
19	Cement, Portland	"	673,989	91,715	1,052,173	738,196	100,352	1,080,644
20	Clay, refractory	Short tons	3,214,989	2,916,501	4,822,483	3,375,738	3,061,794	4,050,885
21	Clay, kaolin	"	30,183	27,382	205,667	24,552	22,246	185,169
22	Coal, anthracite	"	a47,355,387	42,960,116	74,608,885	a52,010,433	47,183,345	80,879,404
23	Coal, bituminous	"	a128,826,364	116,869,397	123,899,415	a117,950,348	106,953,311	103,842,467
24	Coke	"	8,939,961	8,110,245	14,706,544	8,495,295	7,706,846	12,654,558
25	Cobalt oxide	Pounds	3,894	2	5,452	6,550	3	8,843
26	Copperas	Short tons	17,862	16,204	134,520	14,897	13,511	104,160
27	Copper sulphate	Pounds	54,000,000	24,492	1,822,500	e60,000,000	27,215	2,016,000
28	Chrome ore	Long tons	1,629	1,646	16,000	2,653	2,697	33,125
29	Feldspar	"	17,000	17,274	85,000	23,280	23,655	116,400
30	Fluorspar	Short tons	9,700	8,800	63,070	9,000	8,165	64,000
31	Graphite	Pounds	882,912	400	39,731	770,846	349	34,689
32	Graphite, amorphous	Short tons	1,691	1,534	8,996	165	150	1,252
33	Gypsum	"	330,231	299,582	927,615	287,517	260,834	849,925
34	Lime	Bbls., 200 lbs.	e60,000,000	5,443,164	30,000,000	e56,750,000	5,148,336	28,375,000
35	Magnesite	Short tons	1,143	1,037	8,000	1,370	1,243	4,864
36	Manganese ore	Long tons	9,150	9,297	60,000	11,735	11,924	74,890
37	Mica, ground	Pounds	679,000	308	29,522	829,500	377	35,957
38	Mica, sheet	"	6,500	3	5,478	9,900	4	11,103
39	Monazite	"	130,000	59	7,600	750,000	340	45,000
40	Natural gas				14,000,000			11,000,000
41	Paints, mineral	Short tons	44,709	40,559	726,160	38,801	35,200	662,262
42	Paints, vermilion	"	37	34	40,000	41	37	45,600
43	Paints, white lead	"	88,500	80,286	9,469,500	87,242	78,155	8,445,174
44	Paints, zinc oxide	"	25,000	22,679	1,875,000	22,814	20,697	1,711,275
45	Petroleum (crude)	Bbls., 42 gals.	50,349,228	7,043,857	32,223,505	48,527,336	6,788,974	40,762,962
46	Phosphate rock	Long tons	981,340	997,140	3,434,690	952,155	967,485	2,856,465
47	Marls	"	200,000	203,814	540,000	225,000	228,622	607,500
48	Precious stones				200,000			250,000
49	Pyrites	Long tons	95,000	96,529	285,000	107,462	109,192	466,466
50	Salt, evaporated	Bbls., 280 lbs.	9,703,419	1,232,392	4,945,583	9,161,053	1,163,508	4,608,275
51	Salt, rock	"	1,935,642	245,838	678,064	2,341,922	297,438	788,681
52	Silica, sand and quartz	Long tons	300,000	304,814	330,824	315,531	320,610	347,951
53	Slate, roofing	Squares	803,887	237,014	2,926,895	693,944	204,656	2,551,259
54	Slate, other manufactures	Square feet	4,188,920		475,681	5,099,791		499,578
55	Soda, natural	Short tons	2,500	2,268	12,500			
56	Soda, natural sulphate	"	90	82	450			
57	Stone, limestone (flux)	Long tons	3,750,000	3,810,375	2,250,000	3,544,396	3,601,458	2,126,636
58	Stone, marble	Cubic feet	5,639,681	429,399	2,087,758	5,681,766	433,093	2,177,280
59	Stone, onyx	"	2,175	166	28,750	1,450	110	29,000
60	Other building stones				e38,000,000			e30,000,000
	Total non-metals				377,517,086			353,760,877
	METALS.							
61	Aluminum	Pounds	312,000	142	202,800	817,600	371	490,560
62	Antimony	Short tons	350	318	63,000	220	205	39,200
63	Copper	Pounds	327,255,788	148,441	35,179,997	353,504,314	160,392	33,540,489
64	Gold	Troy ounces	1,739,323	*54,093	35,955,000	1,923,619	*59,824	39,761,205
65	Iron, pig	Long tons	7,043,384	7,156,782	93,888,309	6,657,388	6,764,572	71,995,364
66	Lead, value at New York	Short tons	166,678	152,080	12,434,178	160,867	145,906	10,585,048
67	Nickel, fine	Pounds	25,893	*11,745	12,429			
68	Quicksilver	Flasks, 76½ lbs	30,164	1,046	1,108,527	30,440	1,056	1,093,840
69	Silver, commercial value	Troy ounces	60,500,000	*1,881,731	47,311,000	49,846,875	*1,550,387	31,403,531
70	Zinc spelter	Short tons	76,255	69,178	6,214,782	74,004	67,135	5,209,882
	Total metals				232,370,022			194,092,119
	Est. products unspecified				6,000,000			5,500,000
	Grand total				615,847,108			553,352,996

(a) Bituminous coal includes brown coal and lignite. The anthracite production is the total for Pennsylvania, Arkansas and Colorado. (e) Estimated. * Kilograms.

cessful. Users of machine tools in England have become convinced of the superiority of American makes of tools of certain descriptions. This refers particularly to the automatic and universal machines, such as automatic screw and bolt machines and universal grinders. These two are merely mentioned as an indication of the type of machines which find ready sale. The

* From the Secretary's monthly reports.

heavier types of tools, such as mammoth lathes, planers, boring mills and the like, have not as yet found much of a footing abroad. A large sale is carried on in the finer measuring instruments, such as micrometers and vernier calipers, and also in cutting and milling machines. There is also a demand for American hand saws, hack saws, power hack saw machines, vises, lathe chucks, drills and the like.

Those machines of American make which appear to have, in a certain sense, become standard abroad are drill presses, emery grinders, milling machines of the comparatively smaller sizes, and lathes. According to the statement of Mr. ———, those tools which are of a superior design, are perfectly adapted to the work, and which show extreme accuracy in their construction and finish, are the easiest to sell. While attempts have been made in England, and especially in Germany, to copy these tools of the highest grade, the attempt has been unsuccessful, because not enough attention was paid to the accuracy of fit.

Concerning the question as to whether there is any prejudice among managers and workmen in England against American-made tools, Mr. ——— said that at the present time certain makes of American tools are well known over there and are received with pleasure in the shop. Formerly this was not the case, and their introduction was sure to result in ruin, or the attempt to ruin, the machine by the workman placed in charge. But after the workman has become accustomed to the American machine he objects strongly to being placed again in charge of his old machine. The reason is he has found out the superior advantage of the new machine, and for that reason does not care to go back to his old one.

Automatic machines, such as screw machines, several of which are commonly placed in charge of one workman in this country, are run singly in England. This is due to the influence of the trades unions in England. These associations control the men to such an extent that they dictate how many machines the man shall run, and except in special cases they refuse to let him take charge of more than a single appliance. This, in a case of four small milling machines, was got around by the superintendent, who mounted four machines upon one base, this being considered as practically forming one machine, although the capacity of that machine was quadrupled. Nevertheless, it satisfied the demands of the trades unions and prevented trouble.

Building on the "interchangeability of parts" system, so largely in vogue here, has assisted greatly in the introduction of tools abroad. It has been found that duplicate parts could be obtained from the builders cheaper than they could be produced at the English shops. Further than this, and more important, parts so obtained are sure to fit accurately, while those made to order might not.

THE TROLLEY CARS AS LIFE SAVERS.

Everything depends on the point of view from which a subject is examined, as the following communication from a citizen of Brooklyn (where the

victims of the trolley cars, at this writing, considerably exceed 100 in number), lately published in one of the local newspapers, will demonstrate:

"For some reason the newspapers have had a good deal to say in condemnation of the trolley car and its record of 'one hundred fatal accidents' in Brooklyn. It seems to me that the case is not sized up judicially, and that most of the blame is misplaced. Nearly every fatality of this class has resulted from contributory negligence or gross carelessness, or even from suicidal purpose. The trolley has no monopoly as a source of danger. Children who are allowed to run the streets without being properly cautioned, and grown people who, from intoxication or any other cause, tempt fate recklessly, are always liable to disaster, fatal or otherwise. A larger number of people have been drowned by falling into the water from the piers, since the advent of the electric motor, than the trolley has to its credit, yet the papers have failed to harp on the deadly dock.

"The trolley, by lessening the defilement of the streets, has so ameliorated the sanitary condition of the city atmosphere that it has saved many times the number of lives it has destroyed. It has furnished a quick and comfortable transit to the outlying wards, which has reduced the prevalence of grippe and pneumonia among the suburban passengers more than one-half. Many can recall the winter cars with their slush-soaked straw and foul odors, and the tiresome and dangerous delays in the snow, when the passengers were forced to walk in the storm, or even to assist the wretched horses by pushing. Many a man has gone down to his grave from a cold contracted on such a trip. The trolley has saved thousands of lives by enabling the mechanic and clerk to move their little ones from the unwholesome tenements of the city to the pure air and sunshine of the country. It has added, in dozens of ways, to the sum of human welfare. Why, then, does the press persistently attack a system which accomplishes so much good that it has become a great public necessity?"

ARTIFICIAL SILK.

Consul Germain, of Zurich, Switzerland, speaks quite favorably in recent reports to the Department of State (see Consular Reports, Nos. 171 and 173) of the commercial possibilities of the artificial silk made by the process and apparatus devised by Dr. Lehner, of that city. A plant for the manufacture of the product has been erected at Glattbrugg, near Zurich, where the raw material is forwarded to England for manufacture into fabrics.

The accompanying extract from the English Company's prospectus appears in the last-named report of the Consul, viz:

"Lehner's artificial silk is a new material for use in textile manufacture, possessing distinct and valuable characteristics, which render it unique among all fibres hitherto existing. As the result of study and analysis of the natural methods of production of silk by the silkworm, the inventor has, by simple chemical and mechanical means, closely and successfully reproduced a natural process. Wood pulp, cotton or jute waste, etc., are chemically digested and the liquid product is spun by a mechanical silkworm to a thread of even diameter throughout and of unbroken and unlimited length. The

same machine which draws the threads from the liquid twists these threads in any desired number into the requisite 'count,' or thickness of yarn, in one uninterrupted and continuous process, with perfect regularity. The machine is inexpensive and extremely simple. It can be run day and night without intermission, and requires but little power and attention.

"The principal features of this process are: (1) Never-failing supply of the raw material; (2) practically uniform price of same; (3) simplicity of machinery, so as to avoid risk of breakdown; and (4) no skilled, and only a small amount of low-priced, labor is necessary.

"The production of Lehner's artificial silk is entirely independent of climate, temperature, special soil or cultivation.

"Lehner's artificial silk has been spun in Bradford, and has been worked up in a large variety of fabrics. In the dyeing, weaving and finishing of these sample fabrics, no special treatment has been necessary. Unlike most vegetable fibres, Lehner's artificial silk can be dyed in all colors, and the shades obtained excel in brilliancy and delicacy those of the finest natural silk.

"For softness and beauty of appearance the new material equals the best Chinese and Italian silks. By its use, therefore, in combination with cotton, wool or natural silk, brocaded and other ornamental and decorative results can be obtained, which have hitherto been unattainable, except by the employment of the finest trams and the expensive character of these necessarily limits their sale for this purpose. The cost of Lehner s artificial silk being small, it follows that that fibre will open out a large and profitable new field to manufacturers, affording encouragement to them in the production of an unlimited variety of both choice and salable novelties in fabrics of almost every description."

While the operative methods of producing this product apparently differ from those employed in the preparation of the "artificial silk" of Chardonnat, the pioneer inventor in this field, the product itself is doubtless identical, both consisting of a thread of cellulose made by appropriate chemical treatment of filaments of nitrocellulose. The serious objection to this "artificial silk," and which will probably prevent it from being used alone, that is, without admixture with natural fibres, is its deficiency in strength. This defect may, however, not interfere with the use of the product in making mixed fabrics.

POSSIBILITIES OF BEET SUGAR INDUSTRIES.

The beet-sugar industry in the United States is steadily forging ahead, but so enormous is the consumption of sugar that, even with a much more rapid rate of growth, it will be many years before the production of sugar from this and other domestic sources will suffice to meet the home demand. In connection with these remarks, the following data from the *Sugar Beet* will throw some light on the condition of that industry:

"The total area devoted to beets for the seven beet-sugar factories in the United States (this includes the small output of Virginia) was in 1893–94, 19,647 acres, from which were obtained 195,895 tons of beets and 45,191,296 pounds of sugar, corresponding to a yield of 2,300 pounds of sugar per acre, and

an average of 230·7 pounds per ton of beets worked on an average extraction of 11·5 per cent. The average yield of beets per acre was 9·9 tons. Accepting these figures as a basis of calculation for the requirements of the Union, the consumption of sugar during 1894 was 2,024,648 tons, or 4,535,211,520 pounds. To obtain this sugar there would be needed at least 2,000,000 acres of land, if the yield be ten tons to the acre, and, if beets sell for $4 per ton, the money for these roots would represent the enormous sum of $80,000,000 that would be put into circulation among our farming population.

If we admit that farmers receive gratuitously fifty per cent. in weight of beets, furnished by the residual pulp as it leaves the process, this would be sufficient to feed not less than 2,000,000 head of cattle during the three winter months when fodders are most expensive. If we admit two pounds increase per head and diem, there would result 400,000,000 pounds of meat from a product that is now receiving only a limited amount of attention.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, June 19, 1895.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 19, 1895.

Mr. CHARLES BULLOCK, Vice-President, in the chair.

Present, seventy-nine members and eight visitors.

Additions to membership since last report, ten.

The Actuary reported, from the Board of Managers, that an application for the "Boyden Premium" had been received, and that, in accordance with the regulations, a committee of judges appointed by the Board had examined the memoir which accompanied the application, and had reported adversely. The sealed envelope received with the memoir, and supposed to contain the name and address of the applicant, had, in accordance with the rules made and provided for such cases, been destroyed in the presence of the Board. The memoir and report of the judges thereon were submitted with the Actuary's communication.

The action of the Board of Managers in the case was, on motion, unanimously approved.

The paper of the evening was read by Dr. J. F. Holt, on the "High-tension Storage Battery," manufactured by the Holt Electric Storage Company, under the patents of N. H. Edgerton.

The speaker described the special features of construction embodied in this battery, and exhibited specimens of the same adapted to various uses.

The subject was discussed by Messrs. Reed, Walter, Eldridge, Edgerton, and the author. The Chairman expressed the thanks of the meeting to Dr. Holt for his interesting communication. On Mr. Conard's motion, duly seconded, the subject was referred to the Committee on Science and the Arts for investigation and report.

The Secretary presented his monthly report, an abstract of which appears in the June number, and the meeting adjourned.

WM. H. WAHL, *Secretary.*

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

T. F. TOWNSEND, WEATHER BUREAU, OBSERVER IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR MAY, 1895.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 31, 1895.

GENERAL REVIEW.

The average temperature for May, 1895, 60°·6, is 1°·4 above the average [59°·2] for the past seven years.

The highest recorded temperatures occurred on the 30th and 31st, and were as follows: Hollidaysburg, 110°; Lock Haven, 102°; Logania, 101°; and Carlisle, 100°.

The lowest were on the 17th: Smethport, 22°; Shingle House, 23°; Saegerstown, 24°; Wellsboro, 24°; and Dyberry, 24°.

High temperatures prevailed until the 11th, causing rapid growth to vegetation. On the night of the 12th–13th a severe frost occurred, which killed the greater portion of the grape crop and badly injured other fruits. This was followed on the 17th by another damaging frost and freeze, which added additional injury to fruit, corn and early vegetables. Damaging frosts occurred again on the 21st, 22d and 23d. Unusually high temperatures occurred during the balance of the month.

From January 1, 1895, to May 31, 1895, the accumulated deficiency in daily mean temperature at Philadelphia was 295°; at Erie, 327°, and at Pittsburgh, 373°.

For the same period the excess in precipitation, in inches, at Philadelphia, was 0·80; and deficiency at Erie 4·89, and at Pittsburgh, 4·49.

TEMPERATURE.

	Mean Temperature.	*Mean Precipitation, Inches.*
May, 1888	57°·6	4·24
1889	62°·0	5·91
1890	58°·8	6·71
1891	57°·5	2·12
1892	59°·5	5·70
1893	58°·0	5·54
1894	60°·8	8·88
1895	60°·6	2·68

The means of the daily maximum and minimum temperatures, 72°·5 and 48°·6, respectively, give a monthly mean of 60°·6, which is 0°·2 below the corresponding month of 1894.

The average daily range was 23°·9.

Highest monthly mean, 63°·6 at Immel Reservoir (Lycippus) and Pottstown.

Lowest monthly mean, 56°·6 at Shingle House.

Highest temperature recorded during the month, 110° on the 30th at Hollidaysburg.

Lowest temperature, 22° on the 17th at Smethport.

Greatest local monthly range, 85° at Hollidaysburg.

Least local monthly range, 53° at Erie.

Greatest daily range, 52° at Wilkes-Barre.

PRECIPITATION.

The average precipitation for the State, for the month, 2·68 inches, is 2·90 inches less than the average [5·58] for the past seven years.

The rainfall was generally well distributed and timely.

The largest monthly totals of rainfall in inches were: Wellsboro, 6·46; Cassandria, 4·66; Oil City, 4·22; Wilkes-Barre, 4·16; Pottstown, 3·89; and Frederick, 3·76.

The least were: Altoona, 0·80; Beaver Dam, 1·19; Immel Reservoir (Lycippus), 1·34; Greensboro, 1·55; Stoyestown, 1.70; and Brookville, 1·71.

WIND AND WEATHER.

The prevailing wind was from the West.

Average number: rainy days, 9; clear days, 13; fair days, 10; cloudy days, 8.

BAROMETER.

The mean pressure for the month, 30·07, is about ·07 above the normal. At the United States Weather Bureau Stations, the highest observed was 30·36 at Philadelphia on the 1st, and the lowest 29·61 at Harrisburg on the 11th and Erie on the 26th.

MISCELLANEOUS PHENOMENA.

Thunderstorms.—Hollidaysburg, 7th, 8th, 11th, 26th; Le Roy, 7th, 8th, 11th; Towanda, 7th, 8th, 11th; Quakertown, 27th; Cassandria, 7th, 26th; Johnstown, 7th, 8th, 11th; Emporium, 7th, 8th, 26th; East Mauch Chunk, 8th; State College, 7th, 11th, 19th; Coatesville, 27th; Kennett Square, 27th; Westtown, 27th; Lock Haven, 4th, 7th, 8th, 11th, 27th; Saegerstown, 6th, 7th, 11th; Harrisburg, 8th, 11th; Uniontown, 6th, 7th; Huntingdon, 5th, 9th, 10th; Lebanon, 8th, 31st; Coopersburg, 11th, 27th; White Haven, 8th, 11th; Wilkes-Barre, 31st; Williamsport, 7th, 8th, 11th, 31st; Easton, 31st; Aqueduct, Logania, 8th, 11th; *Philadelphia* [Weather Bureau], 27th; [Centennial Avenue], 27th; Blooming Grove, 8th, 11th; Somerset, 7th, 11th; Lewisburg, 8th, 11th; Dyberry, 8th, 11th, 31st; Honesdale, 8th, 25th, 31st; Salem Corners (Hamlinton), 8th, 11th; South Eaton, 8th, 11th.

Hail.—Lock Haven, 4th; Williamsport, 12th.

Frost.—Gettysburg, 13th, 17th; Pittsburgh, 13th, 17th, 20th, 21st, 22d; Hollidaysburg, 13th, 17th, 20th, 22d; Le Roy, 13th, 16th, 17th, 20th, 21st, 22d; Towanda, 16th, 17th, 22d; Forks of Neshaminy, 17th; Quakertown, 16th, 17th, 22d, 23d; Cassandria, 14th, 15th, 17th, 18th, 20th, 22d; Johnstown, 13th, 15th, 17th, 22d, 23d; Emporium, 13th, 16th, 17th, 20th, 21st, 22d, 23d; East Mauch Chunk, 17th, 22d; State College, 13th, 17th, 22d; Coatesville, 17th, 22d; Kennett Square, 15th, 17th; Phœnixville, 13th, 15th, 17th; Westtown, 17th; Lock Haven, 13th, 17th; Saegerstown, 12th, 13th, 14th, 16th, 17th, 18th, 21st, 22d, 23d; Carlisle, 17th; Harrisburg, 17th, 22d; Edinboro, 12th, 21st; Uniontown, 13th, 17th, 22d, 23d, 28th; Chambersburg, 22d; Huntingdon, 17th, 22d; Lebanon, 17th, 22d; Coopersburg, 17th; Drifton, 21st; White Haven, 16th, 17th, 22d, 23d; Wilkes-Barre, 17th; Williamsport, 17th, 22d; Greenville, 13th, 17th, 18th, 21st; Pottstown, 17th; South Bethlehem, 17th; Easton, 17th; Aqueduct, Logania, 2d, 15th, 16th, 17th, 22d, 23d; *Philadelphia* [Weather Bureau], 17th; [Centennial Avenue], 17th; Blooming Grove, 16th, 17th; Shingle House, 13th, 16th, 17th, 20th, 21st, 23d; Selins Grove, 13th, 17th, 21st; Somerset, 10th, 13th, 17th, 18th, 22d; Wellsboro, 13th, 16th, 17th, 18th, 20th, 22d; Lewisburg, 17th, 20th, 22d; Dyberry, 2d, 3d, 13th, 16th, 17th, 20th, 21st, 22d, 23d, 29th; Honesdale, 13th, 14th, 16th, 17th, 22d, 23d; Salem Corners (Hamlinton), 13th, 14th, 15th, 16th, 17th, 18th, 22d; South Eaton, 16th, 22d, 23d; York, 17th.

Sleet.—Le Roy, 12th; Salem Corners (Hamlinton), 12th.

Coronæ.—Towanda, 4th, 5th, 30th.

Solar Halo.—Le Roy, 16th, 17th; Towanda, 15th, 18th; South Bethlehem, 17th; *Philadelphia*, [Weather Bureau], 17th; [Centennial Avenue], 2d, 11th, 17th, 24th; Wellsboro, 17th.

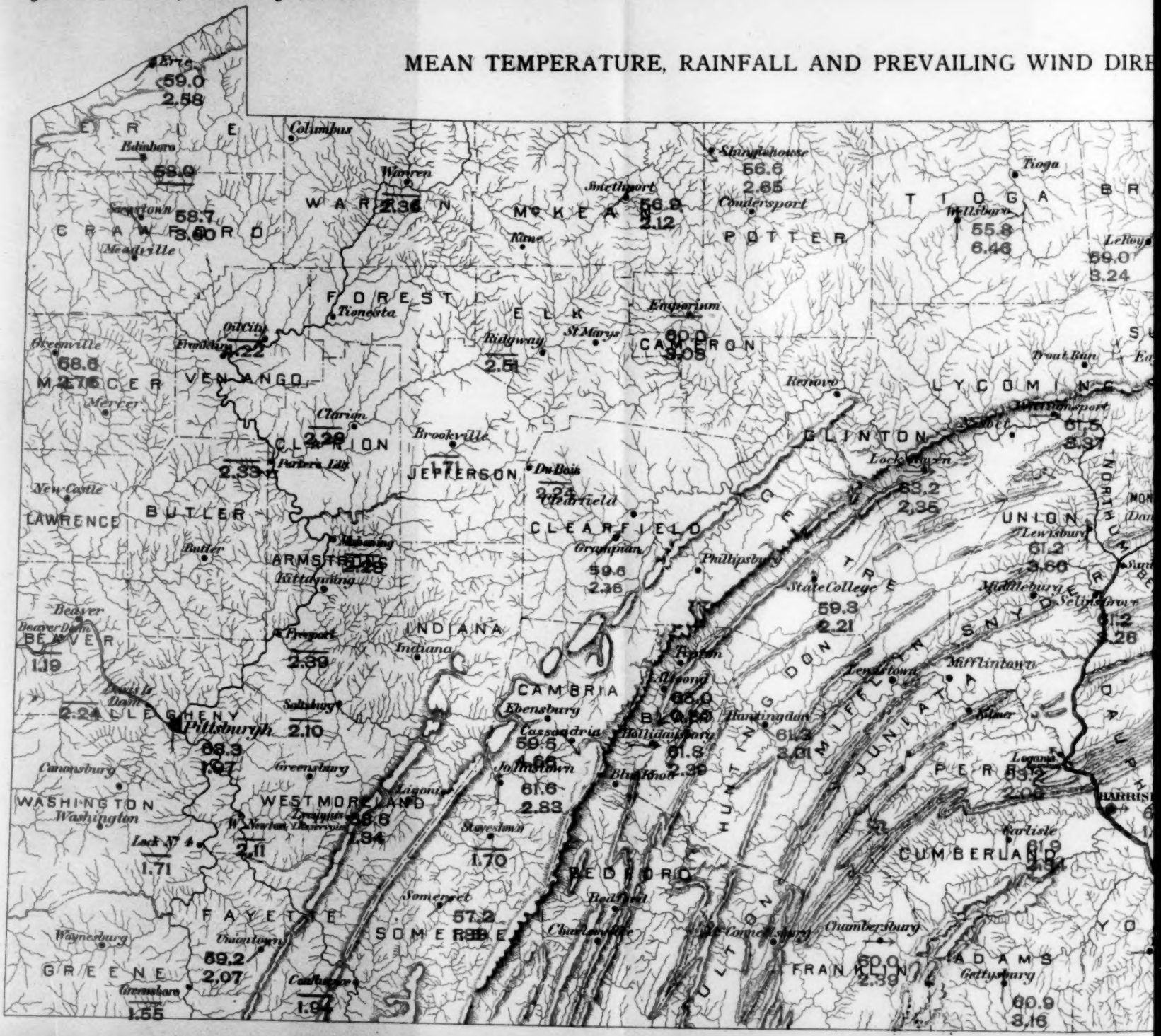
Lunar Halo.—Towanda, 3d; *Philadelphia*, [Weather Bureau], 7th.

Parhelias.—Le Roy, 3d.

Monthly Summary of Reports by Voluntary Observers of the Pennsylvania State Weather Service for May, 1895.

County.	Station.	Elevation above Sea Level (feet).	Temperature.									Precipitation.				Number of Days.			Wind. Prevailing Direction.	Observers
			Mean.	Maximum.		Minimum.		Mean of Maximum.	Mean of Minimum.	Daily Range.		Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rain or Snow.	Clear.	Fair.	Cloudy.		
				Highest.	Date.	Lowest.	Date.			Mean.	Greatest.									
Adams,	Gettysburg,		60·9	94	30	35	17, 24	72·0	49·8	22·2	41	3·16	. . .	. .	13	17	10	4	S	H. F. Buehler.
Allegheny,	Pittsburgh,	820	63·3	93	30	35	22	73·6	53·0	20·6	34	1·97	. . .	. .	10	8	13	10	S	O. D. Stewart, W. B
Berks,	Hamburg,	380	62·2	96	30	33	17	73·9	50·4	23·5	40	3·23	. . .	. .	7	5	16	10	W	William Shipe.
Berks,	Reading,[3]	280	61·8	. . .	. .	. .	. .	. .	. .	. .	. .	2·41	. . .	. .	11	. .	. .	. .	. . .	Franklin Yager.
Blair,	Altoona (30 days),	1,181	65·0	95	31	37	22	75·7	54·3	21·4	41	0·80	. . .	. .	6	. .	. .	. .	. . .	Dr. C. B. Dudley.
Blair,	Hollidaysburg,	947	61·8	110	30	25	22	77·7	45·8	31·9	52	2·39	. . .	. .	9	16	7	8	W	Prof. J. A. Stewart.
Bradford,	Le Roy,	1,400	59·0	91	31	28	13	70·4	47·7	22·7	34	3·24	. . .	. .	10	15	6	10	SW	G. W. T. Warburton.
Bradford,	Towanda,	754	59·6	93	30	27	17	72·3	47·0	25·3	48	2·56	. . .	. .	9	17	4	10	NW	Hiram E. Bull.
Bucks,	Forks of Neshaminy[1] (27 days),	304	60·7	. . .	. .	. .	. .	. .	. .	. .	. .	2·70	. . .	. .	9	16	. .	11	N	J. C. Hilsman.
Bucks,	Quakertown,	536	59·5	95	30	29	17	71·7	47·3	24·4	41	3·60	. . .	. .	8	11	12	8	NW	J. L. Heacock.
Cambria,	Cassandria	2,100	59·5	88	30	31	22	67·3	51·7	15·6	30	4·66	T	. .	10	15	8	8	NW	A. H. Boyle.
Cambria,	Johnstown,	1,184	61·6	94	31	30	17	75·1	48·1	27·0	42	2·83	T	. .	12	14	7	10	S	E. C. Lorentz.
Cameron,	Emporium,	1,050	60·0	98	30	27	17, 22	74·2	45·8	28·4	46	3·08	T	. .	8	16	8	7	W	T. B. Lloyd.
Carbon,	E. Mauch Chunk,	550	60·8	97	30	28	17	74·2	47·3	26·9	47	2·98	. . .	. .	11	19	7	5	W	F. C. Wintermute.
Centre,	State College—Agricultural Experiment Sta.,	1,191	59·3	93	30	31	13	69·2	49·4	19·8	30	2·21	. . .	. .	10	9	12	10	S	Prof. Wm. Frear.
Chester,	West Chester,	455	61·4	92	30, 31	38	17, 22	70·9	51·9	19·0	30	3·30	. . .	. .	11	16	4	11	W	J. C. Green, D.D.S.
Chester,	Coatesville,	380	61·4	95	31	30	17	73·3	49·4	23·9	40	3·65	. . .	. .	8	13	14	4	S	W. T. Gordon.
Chester	Kennett Square,	275	61·2	94	31	34	17	72·9	49·5	23·4	37	3·30	. . .	. .	12	14	8	9	NW	B. P. Kirk.
Chester,	Phœnixville,†	190	. . .	. .	. .	35.	17, 20	. . .	. .	. .	. .	3·44	. . .	. .	9	11	8	12	SW	T. Knowles Perot.
Chester,	Westtown (30 days),	350	59·9	92	31	34	17	69·9	49·9	20·0	35	3·34	. . .	. .	8	7	16	7	W	John D. Carter.
Clearfield,	Grampian,†	1,450	59·6	94	31	26	13	72·0	47·1	24·9	38	2·38	. . .	. .	10	7	15	9	SW	Nathan Moore.
Clinton,	Lock Haven,[1]	560	63·2	102	30	30	22	. . .	. .	. .	. .	2·35	. . .	. .	9	20	6	5	W	Prof. J. A. Robb.
Crawford,	Saegerstown,	1,200	58·7	94	5	24	22	75·2	42·2	33·0	48	3·60	T	. .	8	10	10	11	NW	J. G. Apple.
Cumberland,	Carlisle,	480	61·9	100	30	32	17	73·0	50·8	22·2	39	2·34	. . .	. .	10	16	9	6	S	J. E. Pague.
Dauphin,	Harrisburg,	480	62·0	95	30	37	17	71·0	52·0	19·0	35	1·98	. . .	. .	11	21	3	7	W	F. Ridgway, W. B.
Delaware,	Swarthmore—Swarthmore College‡,	361	. . .	. .	. .	. .	. .	. .	. .	. .	. .	2·04	. . .	. .	5	. .	. .	. .	. . .	Prof. S. J. Cunningham,
Erie,	Edinboro,*[1]	190	58·0	89	5	26	12	. . .	. .	. .	. .	. .	. . .	. .	. .	. .	. .	. .	W	C. F. Sweet.
Erie,	Erie,	1,400	59·0	85	31	32	13	67·0	51·0	16·0	36	2·58	. . .	. .	9	12	13	6	SW	P. Wood, W. B.
Fayette,	Uniontown (29 days),	681	59·2	90	5	29	22	70·7	47·7	23·0	36	2·07	. . .	. .	7	11	16	2	SW	Wm. Hunt.
Franklin,	Chambersburg,	1,000	60·0	96	30	30	17	72·4	47·6	24·8	42	2·39	. . .	. .	11	8	9	14	W	J. C. Boggs.
Huntingdon,	Huntingdon—The Normal College,	650	61·3	98	30	25	14	76·5	46·1	30·4	48	3·01	. . .	. .	8	2	23	6	SE	Prof. W. J. Swigart.
Lancaster,	Lancaster—Franklin and Marshall Col'ge,	413	61·2	93	30, 31	36	22	71·8	50·6	21·2	33	3·01	. . .	. .	11	16	8	7	W	A. V. Heister.
Lebanon,	Lebanon,	458	61·0	96	30	32	17	72·6	49·3	23·3	40	1·85	. . .	. .	11	10	12	9	SW	G. W. Hayes, C. E.
Lehigh,	Coopersburg,	520	60·7	89	30, 31	35	17	70·5	50·9	19·6	32	3·08	. . .	. .	11	13	13	5	SE	Dr. M. H. Boye.
Luzerne,	Drifton (26 days),	1,683	57·8	93	31	29	17, 21	71·2	44·5	26·7	50	2·03	. . .	. .	6	7	12	7	N	J. R. Wagner.
Luzerne,	White Haven,		57·6	91	30, 31	26	17	70·4	44·7	25·7	43	2·75	. . .	. .	5	9	17	5	S	C. M. Driggs.
Luzerne,	Wilkes-Barre,	575	62·4	97	30	30	17, 21	77·8	47·0	30·8	52	4·16	. . .	. .	7	15	6	10	W	A. W. Betterly.
Lycoming,	Williamsport,		61·5	96	30	33	17, 22	72·1	50·9	21·2	42	3·37	. . .	. .	9	18	8	5	W	G. D. Snyder, C. E.
McKean,	Smethport,	1,500	56·9	94	30	22	17	71·8	42·0	29·8	46	2·12	. . .	. .	10	10	14	7	SW	Armstrong & Brownell.
Mercer,	Greenville—Thiel College,	1,000	58·6	94	30	25	21	72·2	45·0	27·2	40	2·75	. . .	. .	7	21	2	8	. . .	Prof. S. H. Miller.
Montgomery,	Pottstown,	150	63·6	97	31	36	17	74·5	52·6	21·9	36	3·89	. . .	. .	6	14	13	4	S	Charles Moore, D.D.S.
Northampton,	South Bethlehem,	339	62·6	97	30	36	17	74·8	50·5	24·3	39	. . .	. . .	. .	. .	13	9	9	SW	T. Merriman.
Northampton,	Easton—Lafayette College,	325	61·4	93	30, 31	33	17	72·7	50·1	22·6	38	2·58	. . .	. .	8	17	6	8	. . .	J. W. Moore.
Perry,	(Aqueduct) Logania,	367	63·2	101	30, 31	31	17	75·2	51·2	24·0	46	2·06	. . .	. .	11	13	9	9	SE	Richard Callin.
Philadelphia,	U. S. Weather Bureau.	117	62·4	94	30	40	13	71·5	53·3	18·2	29	1·72	. . .	. .	9	8	17	6	NW	L. M. Dey, W. B.
Philadelphia,	1529 Centennial Avenue,	120	63·0	96	31	40	2, 13	73·0	52·9	20·1	31	2·03	. . .	. .	8	8	17	6	NW	John Comly.
Pike,	Blooming Grove,*[1]	. . .	60·0	94	30	36	13	. . .	. .	. .	. .	2·74	. . .	. .	8	5	21	5	S	John Grathwohl.
Potter,	Shingle House,	1,475	56·6	93	30	23	16, 17	71·6	41·7	29·9	48	2·65	. . .	. .	8	18	3	10	NW	H. L. Pearsall.
Snyder,	Selins Grove,	455	61·2	96	31	29	17	75·9	46·5	29·4	45	3·26	. . .	. .	10	. .	22	9	SW	J. M. Boyer.
Somerset,	Somerset (30 days),	2,250	57·2	92	30	25	17	71·5	42·8	28·7	40	1·88	. . .	. .	3	3	19	8	SW	W. M. Schrock.
Tioga,	Wellsboro,*[1]	1,327	55·8	92	30	24	17	. . .	. .	. .	. .	6·46	. . .	. .	13	13	3	15	S	H. D. Deming.
Union,	Lewisburg	450	61·2	99	30	30	17	74·7	47·7	27·0	46	3·66	. . .	. .	9	12	10	9	S	Prof. W. G. Owen.
Wayne,	Dyberry,	1,100	56·8	90	30, 31	24	17	71·1	42·4	28·7	51	2·52	. . .	. .	7	14	10	7	W	Theodore Day.
Wayne,	Honesdale,	1,000	58 6	91	30	28	17	70·3	46·8	23·5	40	2·89	. . .	. .	11	16	9	6	NW	Andrew Thompson
Wayne,	(Salem Corners) Hamlinton,	1,600	59·8	96	31	30	13, 22	70·5	49·0	21·5	37	2·87	T	. .	14	9	9	13	W	T.B. Orchard, M D.
Westmoreland,	(Immel Reservoir) Lycippus,	1,420	63·6	92	31	37	13	72·5	54·7	17·8	41	1·34	. . .	. .	6	. .	. .	. .	. . .	Murray Forbes.
Wyoming,	South Eaton,	660	59·9	90	30, 31	30	22	71·7	48·1	23·6	42	3·40	. . .	. .	7	17	3	11	NW	B. M. Hall.
York,	York,	385	61·4	95	30	34	17, 22	72·7	50·1	22·6	35	2·73	. . .	. .	13	15	11	5	W	Mrs. L. H. Grenewald.

Mean temperature from maximum and minimum readings. * Extremes from dry thermometers. [1] Mean temperatures, 7 + 2 + 9 + 9 + 4 [2] Mean temperature 8 + 8 + 2.
† No records. ‡ Records incomplete.


MEAN TEMPERATURE, RAINFALL AND PREVAILING WIND DIRE
Erie
59.0
2.58
ERIE
Columbus
Edinboro
58.0
Warren
WARREN
Sheffield
Shinglehouse
56.6
2.65
Coudersport
McKEAN
56.8
2.12
TIOGA
Tioga
Wellsboro
55.8
6.46
LeRoy
59.0
3.24
Meadville
CRAWFORD
Kane
POTTER
FOREST
ELK
Tionesta
Emporium
Oil City
Franklin
Ridgway
St Marys
CAMERON
Greenville
68.6
MERCER
VENANGO
Mercer
Clarion
CLARION
Brookville
JEFFERSON
Parker's Ldg
New Castle
LAWRENCE
BUTLER
Du Bois
Clearfield
CLEARFIELD
Renovo
LYCOMING
Boat Run
Williamsport
Lock Haven
CLINTON
UNION
Lewisburg
Butler
ARMSTRONG
Kittanning
Graham
Phillipsburg
State College
Middleburg
Selinsgrove
Beaver
Beaver Dam
BEAVER
1.19
Freeport
INDIANA
Indiana
Reedsville
Lewistown
Mifflintown
Dunlo
Pittsburgh
68.3
Saltsburg
2.10
CAMBRIA
Ebensburg
Cassandria
59.5
Hollidaysburg
61.8
Huntingdon
61.3
Kittanning
Canonsburg
Greensburg
Johnstown
61.6
2.83
Blue Knob
PERRY
Loysville
WASHINGTON
Washington
WESTMORELAND
Ligonier
Stoystown
1.70
Lock № 4
1.71
FAYETTE
Somerset
57.2
BEDFORD
Bedford
Carlisle
CUMBERLAND
Waynesburg
Uniontown
59.2
2.07
SOMERSET
Chambersburg
FRANKLIN
60.0
2.39
ADAMS
Gettysburg
60.9
3.16
Greensboro
1.55
GREENE

RATURE, RAINFALL AND PREVAILING WIND DIRECTION

ECTION FOR MAY, 1895.